Notice No.3

Rules and Regulations for the Classification of Special Service Craft

July 2019

The status of this Rule set is amended as shown and is now to be read in conjunction with this and prior Notices. Any corrigenda included in the Notice are effective immediately.

Please note that corrigenda amends to paragraphs, Tables and Figures are not shown in their entirety.

Issue date: November 2019

Amendments to	Effective date	IACS/IMO implementation (if applicable)
Part 10, Chapter 1, Section 2	1 January 2020	1 January 2020
Part 10, Chapter 1, Section 7	1 January 2020	1 January 2020
Part 11, Chapter 2, Section 4	1 January 2020	1 January 2020
Part 15, Chapter 1, Section 5	1 January 2020	1 January 2020
Part 15, Chapter 3, Section 14	1 January 2020	N/A
Part 16, Chapter 1, Sections 1 & 2	1 January 2020	N/A
Part 16, Chapter 2, Sections 1, 9, 12, 17, 21 & 23	1 January 2020	N/A

Lloyd's
Register

Part 10, Chapter 1
Reciprocating Internal Combustion Engines

■ *Section 2*
Materials and components

2.2 Testing and inspection

2.2.1 Materials and components for engines are to be manufactured, tested and documented in accordance with *Table 1.2.1 Summary of testing and associated documentation for engine components* under a quality control system that is suitable for the actual engine types to be certified by LR. *See also* *Pt 10, Ch 2, 2.2 Testing and inspection 2.2.8* and the applicable requirements specified in the *Rules for the Manufacture, Testing and Certification of Materials, July 2019*.

2.2.3 The testing and inspection in *Table 1.2.1 Summary of testing and associated documentation for engine components* is to be documented by the manufacturer (e.g. manufacturer certified materials testing or manufacturer issued NDT report as applicable), except where LR intervention is explicitly required, in which case an LR Component Certificate is to be issued which confirms conformity with the Rule requirements, with tests carried out on either the finished component itself or on samples taken from earlier stages in the production of the component, as applicable.

2.2.5 Where *Table 1.2.1 Summary of testing and associated documentation for engine components* states that a test report is required, this is to be issued by the manufacturer and provided for review by the Surveyor. The report is to identify the samples from the current production batch that have been tested and inspected to confirm that the component complies with all applicable requirements.

2.2.6 Where a manufacturer’s document (test certificate or NDT report) is required in *Table 1.2.1 Summary of testing and associated documentation for engine components*, this is to be issued by the manufacturer and provided for review by the Surveyor. The document is to comply with the requirements of the *Rules for the Manufacture, Testing and Certification of Materials, July 2019, Ch 1, 3.1 General 3.1.3(c)* or *Ch 1, 5.5 Non-destructive examination reports 5.5.1* as applicable and is to identify the tests and inspections that have been carried out on the finished component itself or, where applicable, on samples taken from earlier stages in the production of the component.

2.2.8 ~~All material~~ Where an LR material certificate is specified for components listed in *Table 1.2.1 Summary of testing and associated documentation for engine components*, the material is to be from an LR approved manufacturer, and manufactured within the scope of approval of that manufacturer, except where explicitly stated otherwise in other Parts and Chapters of the Rules.

(Part only shown)

Table 1.2.1 Summary of testing and associated documentation for engine components

Part	**Material properties *see* Note 2**	**Non-destructive examination**	**Hydraulic testing *see* Note 4**	**Dimensional inspection *see* Note 3**	**Visual inspection**	**Applicable to engines**	**Final document to be issued**
Cylinder block (grey cast iron or spheroidal graphite cast iron)	-	-	W (P) *see* Note 6	-	-	~~Crosshead~~ >400kW/cylinder	W Hydraulic Test Certificate
Piston rod	LR(C + M)	W (UT + CD)	-	-	LR(V) (Random)	Crosshead B>400mm	LR Component Certificate
High pressure fuel injection system – ~~valve and~~ pump body (pressure side) *see* Notes 10 1 and 11	~~-~~ W(C + M)	-	W (Lesser of P or p+30 MPa	-	-	B>300mm	W Material Properties Certificate W Hydraulic Test Certificate or Test Report. *See* Note 14
			TR (Lesser of P or p+30 MPa)			B≤300mm	
High pressure fuel injection system – valves *see* Note 10	-	-	W (Lesser of P or p+30 MPa	-	-	B>300mm	W Hydraulic Test Certificate or Test Report. *See* Note 14
			TR (Lesser of P or p+30 MPa)			B≤300mm	
High pressure fuel injection pipes including common rail *see* Note 10	W(C + M)	-	W (Lesser of P or p+30 MPa)	-	-	B>300mm	W Material Properties Certificate W Hydraulic Test Certificate or Test Report. *See* Note 14
			TR (Lesser of P or p+30 MPa)			B≤300mm	
High pressure common servo oil	W(C + M)	-	W (Lesser of P	-	-	B>300mm	W Material

system			or p+30 MPa)				Properties Certificate W Hydraulic Test Certificate or Test Report. *See* Note 14
			TR (Lesser of P or P+30 MPa)			B≤300mm	
Coolers, both sides *see* Note 12	W(C + M)	-	W (P)	-	-	B>300mm	W Material Properties Certificate W Hydraulic Test Certificate. *See* Note 14
Accumulator ~~of common rail fuel or servo oil system~~	W(C + M)	-	W (Lesser of P or p+30 MPa)	-	-	Accumulators with a capacity >0,5l	W Material Properties Certificate W Hydraulic Test Certificate. *See* Note 14
Piping, pumps, actuators, etc., for hydraulic drive of valves, if applicable	W(C + M)	-	W (P)	-	-	>800kW/cylinder	W Material Properties Certificate W Hydraulic Test Certificate. *See* Note 14
Engine-driven pumps (oil, water, fuel, bilge) excluding those listed separately above	-	-	W (P)	-	-	>800kW/cylinder	W Hydraulic Test Certificate. *See* Note 14

SYMBOLS:

B = Bore dimension, refers to engine cylinder bores

C = Chemical composition analysis

M = Mechanical property analysis

UT = Ultrasonic testing (*see* Note 1)

CD = Crack detection by MPI or DPT (*see* Note 7)

W ( ) = Test/inspection to be certified by manufacturer

p = Maximum working pressure of item concerned

P = Pressure test at 1,5*p*

V = Visual examination of accessible surfaces

LR( ) = Test/inspection to be certified by LR

TR[ ] = Test report required for process in brackets (*see ~~Pt 5, Ch 2~~,Pt 10, Ch 1, 2.2 Testing and inspection 2.2.6*)

Note 14. Material certification requirements for pumps and piping components are dependent on the operating pressure and temperature. Requirements given in this Table apply except where alternative requirements are explicitly given elsewhere in the Rules. *See Pt 15, Ch 1, 11.1 Metallic materials.*

■ *Section 7*
Control and monitoring of main, auxiliary and emergency engines

7.1 General

(Part only shown)
7.1.2 Oil mist detection or bearing temperature monitoring (or equivalent device in accordance with SOLAS II-1, Regulation 47.2) fitted as required by *Pt 10, Ch 1, 10.8 Oil mist detection 10.8.1* are to operate as follows:

(e) Where engine bearing temperature monitors or equivalent devices in accordance with SOLAS II-1, Regulation 47.2 are provided for the prevention of the build-up of oil mist that may lead to a potentially explosive condition within the crankcase, details are to be submitted for consideration. The submission is to demonstrate that the arrangements are equivalent to those provided by oil mist detection, *see Pt 10, Ch 1, 10.8 Oil mist detection ~~10.8.14~~ 10.8.15*.

Where required, for each trunk piston engine, one oil mist detector (or engine bearing temperature monitoring system or equivalent device) having two independent outputs for initiating the alarm and shutdown would satisfy the requirement for independence between alarm and shutdown systems.

7.2 Main engine governors

7.2.3 When electronic speed governors of main internal combustion engines form part of a remote control system, they are to comply with the following conditions:

(a) If lack of power to the governor may cause changes in the present speed and direction of thrust of the propeller, which consequently compromise safe operation of the vessel, then backup power supply is to be provided;

(b) Local control of the engines is always to be possible. A means to effect safe transfer of control to the local control position and then control the engine is to be available in all normal and reasonably foreseeable abnormal conditions;

(c) In addition, electronic speed governors and their actuators are to be type approved in accordance with LR's Type Approval System Test Specification Number 1.

7.3 Auxiliary and emergency engine governors

Existing paragraphs 7.3.1 to 7.3.5 have been deleted and replaced with below.

7.3.1 Prime movers for driving generators of the main and emergency sources of electrical power are to be fitted with a speed governor which will prevent transient frequency variations in the electrical network in excess of ±10 per cent of the rated frequency, with a recovery time to steady state conditions not exceeding 5 seconds, when the maximum electrical step load is switched on or off.

7.3.2 In the case when a step load equivalent to the rated output of a generator is switched off, a transient speed variation in excess of 10 per cent of the rated speed may be acceptable, provided that this does not cause the intervention of the overspeed device as required by *Pt 10, Ch 1, 7.4 Overspeed protective devices*.

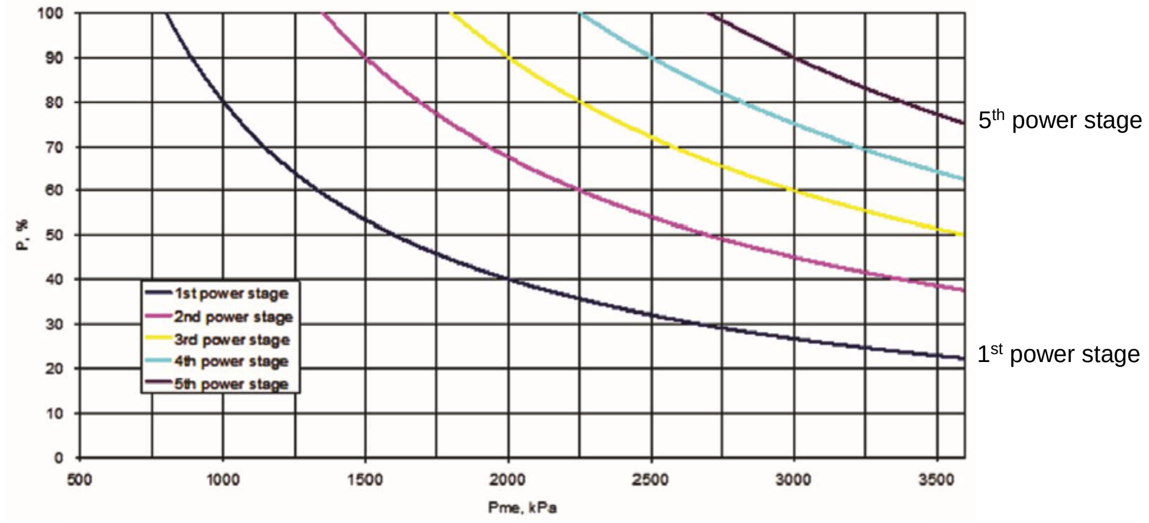
7.3.3 At all loads between no load and rated power, the permanent speed variation should not be more than ±5 per cent of the rated speed.

7.3.4 Prime movers are to be selected in such a way that they will meet the load demand within the ship's power distribution system. Application of electrical load should be possible with two load steps and must be such that prime movers, running at no load, can suddenly be loaded to 50 per cent of the rated power of the generator followed by the remaining 50 per cent after an interval sufficient to restore the speed to steady state. Steady state conditions should be achieved in not more than 5 seconds. Steady state conditions are those at which the envelope of speed variation does not exceed +1 per cent of the declared speed at the new power.

7.3.5 Application of electrical load in more than two load steps can only be permitted if the conditions within the ship's power distribution system permit the use of such prime movers which can only be loaded in more than two load steps (*see Figure 1.7.1 Reference values for maximum possible sudden power increase (four-stroke engines)*) and provided that this is already allowed for at the design stage. This is to be verified in the form of system specifications to be approved and to be demonstrated at ship's trials. In this case, due consideration is to be given to:

(a) The power required for the electrical equipment to be automatically switched on after blackout and to the sequence in which it is connected.

(b) Where generators are to be operated in parallel and where the power has to be transferred from one generator to another in the event of any one generator being switched off.



P_{me} : mean effective pressure at declared power

P : power increase referred to declared power at site conditions

Figure 1.7.1 Reference values for maximum possible sudden power increase (four-stroke engines)

7.3.6 Emergency generator sets are to comply with the requirements of *Pt 10, Ch 1, 7.3 Auxiliary engine governors 7.3.1* to *Pt 10, Ch 1, 7.3 Auxiliary engine governors 7.3.3* even when:

(a) their total consumer load is applied suddenly; or

(b) their total consumer load is applied in steps, subject to:

- the total load being supplied within 45 seconds of power failure on the main switchboard;
- the maximum step load being declared and demonstrated;
- the power distribution system being designed such that the declared maximum step loading is not exceeded; and
- the compliance of time delays and loading sequence with the above being demonstrated at ship's trials.

7.3.7 For a.c. generating sets operating in parallel, the governing characteristics of the prime movers shall be such that within the limits of 20 per cent and 100 per cent total load, the load on any generating set will not normally differ from its proportionate share of the total load by more than 15 per cent of the rated power of the largest machine, or 25 per cent of the rated power of the individual machine in question, whichever is the less. For an a.c. generating set intended to operate in parallel, facilities are to be provided to adjust the governor sufficiently finely to permit an adjustment of load not exceeding 5 per cent of the rated load at normal frequency.

7.3.8 For generator set voltage control requirements *see Pt 16, Ch 2, 9.4 Generator control*.

7.3.9 For quality of power supplies (QPS) requirements *see Pt 16, Ch 2, 1.8 Quality of power supplies.*

7.6 Engines for propulsion purposes

(Part only shown)

Table 1.7.1 Engines for propulsion purposes: Alarms and slow-downs

Item	Alarm	Note
~~Oil mist concentration in crankcase or bearing temperature~~ Activation of oil mist detection arrangements (or activation of the temperature monitoring systems or equivalent devices of: - the engine main, crank and crosshead bearing oil outlet; or - the engine main, crank and crosshead bearing)	High	~~*See Pt 10, Ch 1, 7.1 General 7.1.2.* Automatic slow-down of crosshead engines, for trunk piston engines *see Table 1.7.2 Engines for propulsion purposes: Automatic shutdowns.*~~ For crosshead engines, automatic slow-down. For trunk-piston engines, *see Table 1.7.2 Engines for propulsion purposes: Automatic shutdowns. See also Pt 10, Ch 1, 7.1 General 7.1.2*.

(Part only shown)

Table 1.7.2 Engines for propulsion purposes: Automatic shutdowns

Item	Alarm	Note
~~Oil mist concentration in crankcase or bearing temperature~~ Activation of oil mist detection arrangements (or activation of the temperature monitoring systems or equivalent devices of: - the engine main and crank bearing oil outlet; or - the engine main and crank bearing)	High	~~*See Pt 10, Ch 1, 7.1 General 7.1.2* Automatic shutdown of trunk piston engines, for crosshead engines *see Table 1.7.1 Engines for propulsion purposes: Alarms and slow-downs*~~ For trunk piston engines, automatic shutdown. For crosshead engines, *see Table 1.7.1 Engines for propulsion purposes: Alarms and slow-downs. See also Pt 10, Ch 1, 7.1 General 7.1.2.*

7.7 Auxiliary engines

(Part only shown)

Table 1.7.3 Auxiliary engines: Alarms and safeguards

Item	Alarm	Note
~~Oil mist concentration in crankcase or bearing temperature~~ Activation of oil mist detection arrangements (or activation of the temperature monitoring systems or equivalent devices of: - the engine main and crank bearing oil outlet; or - the engine main and crank bearing)	High	Automatic shutdown of engine, *see also Pt 10, Ch 1, 7.1 General 7.1.2*

7.8 Emergency engines

(Part only shown)

Table 1.7.4 Emergency engines: Alarms and safeguards

Item	Alarm for engine power < 220 kW	Alarm for engine power ≥ 220 kW	Note
~~Oil mist concentration in crankcase~~ Activation of oil mist detection arrangements (or activation of the temperature monitoring systems or equivalent devices of: - the engine main and crank bearing oil outlet; or - the engine main and crank bearing)	—	High	*See* Note
Note For engines having a power of more than 2250 kW or a cylinder bore of more than 300 mm.			

Part 11, Chapter 2
Shafting Systems

■ *Section 4*
Design and construction

4.16 Sternbushes and sterntube arrangements

4.16.3 Synthetic materials for application as water lubricated stern tube bearings are to be approved in accordance with *Rules for the Manufacture, Testing and Certification of Materials, July 2019, Ch 14, 2.13 Sterntube bearings 2.13.1.*

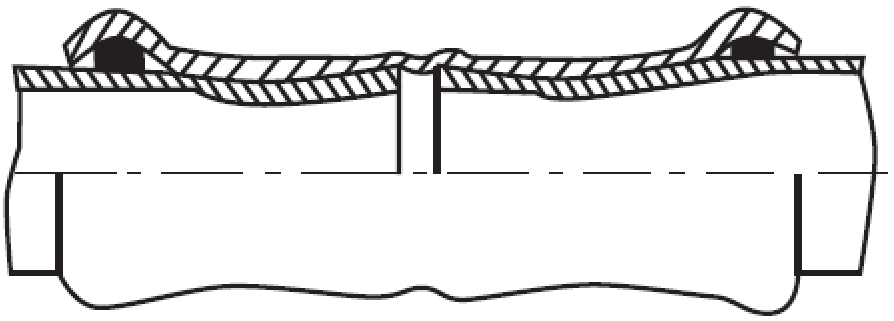
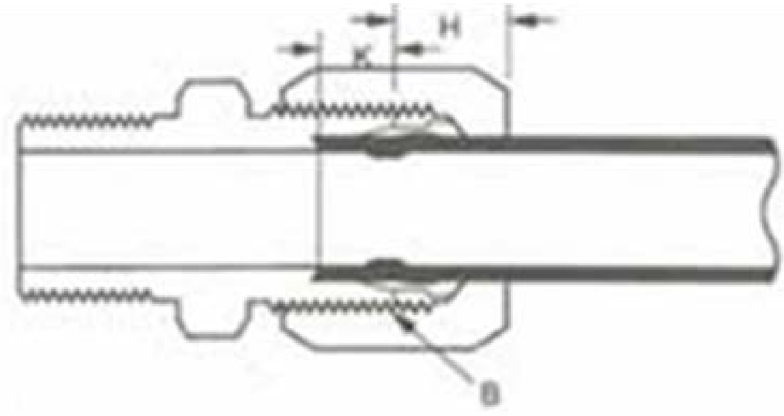
Existing paragraphs 4.16.3 to 4.16.10 have been renumbered 4.16.4 to 4.16.11.

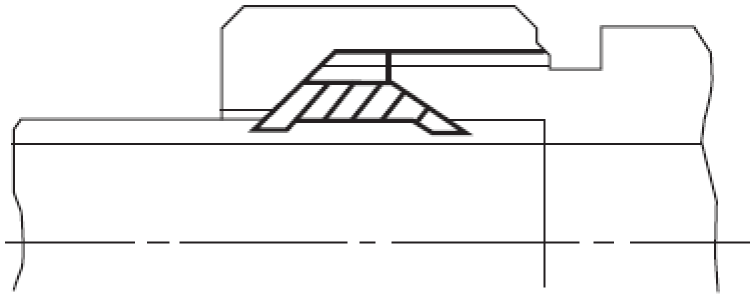
Part 15, Chapter 1
Piping Design Requirements

■ *Section 5*
Carbon and low alloy steels

5.8 Other mechanical couplings

Figure 1.5.2 Examples of mechanical joints (Part 1)

Press Type	
Typical Compression Type	

Bite Type	

(Part only shown)

Table 1.5.6 Application of mechanical joints

Note 2. Slip on joints are not accepted in side machinery spaces of category A or accommodation spaces. They may be accepted in other machinery spaces provided the joints are located in easily visible and accessible positions. ~~Mechanical joints that include any components which readily deteriorate in case of fire are not permitted machinery spaces of category A or accommodation spaces. Mechanical joints that include any components which readily deteriorate in case of fire that are of an approved fire-resistant type may be fitted in other machinery spaces provided the joints are located in easily visible and accessible positions.~~

Note 3. ~~Mechanical joints that include any components which readily deteriorate in case of fire fitted on fuel oil lines are to be of an approved fire-resistant type. Mechanical joints that include any components which readily deteriorate in case of fire fitted on other systems are to be of an~~ Mechanical joints are to be of an approved fire-resistant type except when they are fitted on open decks having little or no fire risk as defined in SOLAS II-2/Reg. 9.2.3.3.2.2(10).

(Part only shown)

Table 1.5.7 Application of mechanical joints depending upon the class of piping

Type of joints	**Classes of piping systems**		
	Class I	Class II	Class III
Compression Couplings			
Swage type	+	+	+
Bite type	+ (OD ≤ 60,3mm)	+ (OD ≤ 60,3mm)	+
Typical compression type	+ (OD ≤ 60,3mm)	+ (OD ≤ 60,3mm)	+
Flared type	+ (OD ≤ 60,3mm)	+ (OD ≤ 60,3mm)	+
Press type	-	-	+

Part 15, Chapter 3
Machinery Piping Systems

■ *Section 14*
Emissions abatement ~~systems~~ plant

14.1 General

14.1.1 Where any aspect of the design or construction of an emissions abatement plant is not covered by this Section, the relevant requirements of the *Rules and Regulations for the Classification of Ships, July 2019* or the *Rules and Regulations for the Classification of Naval Ships, January 2019* are to be applied as considered necessary as described in *Pt 1, Ch 2, 2.1 Definitions 2.1.6*.

Existing paragraph 14.1.1 has been renumbered 14.1.2.

Part 16, Chapter 1
Control Engineering Systems

■ *Section 1*
General requirements

1.2 Documentation required for design review

(Part only shown)

1.2.2 A description of operation with explanatory diagrams together with line diagrams of control circuits, list of monitored, control and alarm points is required for the following machinery or equipment:

- Controllable pitch propellers.
- Electric generating plant.
- Lithium battery system installations, *see also Pt 16, Ch 2, 1.2 Documentation required for design review 1.2.13*.
- Thrust units.
- ~~Waterjets~~ Water jets for propulsion purposes.

■ *Section 2*
Essential features for control, alarm, monitoring and safety systems

2.8 Fire detection and fire alarm systems

2.8.1 Fire detection and ~~fire-alarm~~ fire alarm systems are to comply with *Chapter 9 – Fixed fire detection and fire alarm systems* of the *Fire Safety Systems Code* (FSS Code), Part 17 Fire Protection, Detection and Extinction and ~~*Pt 16, Ch 1, 2.8 Fire detection alarm systems 2.8.2*~~ the requirements in this Section as applicable.

2.8.2 Fire detection control units, indicating panels, detector heads, manual call points and short-circuit isolation units are to be ~~T~~type ~~A~~approved in accordance with Test Specification Number 1 given in LR's *Type Approval* System for an environmental category appropriate for the locations in which they are intended to operate. ~~For addressable systems, *see also Pt 16, Ch 1, 2.10 Programmable electronic systems – General requirements*.~~

2.8.8 It is to be demonstrated to the Surveyor's satisfaction that detector heads are so located that air currents will not render the system ineffective whether the ~~ship~~craft is at sea or in port.

2.8.10 Where an automatic fire detection system is to be fitted in a machinery space, the requirements of *Pt 16, Ch 1, 2.8 Fire detection alarm systems 2.8.11* to *Pt 16, Ch 1, 2.8 Fire detection alarm systems 2.8.15* are also to be satisfied. *See also* SOLAS 1974, as amended Chapter II-2, Part C,~~.~~ *Regulation 7 - Detection and alarm*, or ~~Chapter 4~~ Part 17 Fire Protection, Detection and Extinction as applicable.

2.9 Fixed water-based local application fire-fighting systems

2.9.2 Systems are to be available for immediate use and arranged for manual activation from inside and outside the protected space. *See also* ~~Pt 16, Ch 1, 2.9 Fixed water-based local application fire-fighting systems 2.9.2~~ *Pt 16, Ch 2, 17.3 Fixed water-based local application fire-fighting systems 17.3.4*.

2.9.8 Where, additionally, the system is required to be capable of automatic release, the arrangements are to be in accordance with ~~*Pt 16, Ch 1, 2.9 Fixed water-based local application fire-fighting systems 2.9.8*~~ *Pt 16, Ch 1, 2.9 Fixed water-based local application fire-fighting systems 2.9.9* to *Pt 16, Ch 1, 2.9 Fixed water-based local application fire-fighting systems 2.9.12*.

Part 16, Chapter 2
Electrical Engineering

■ *Section 1*
General requirements

1.2 Documentation required for design review

1.2.1 The documentation described in *Pt 16, Ch 2, 1.2 Documentation required for design review 1.2.2* to *Pt 6, Ch 2, 1.2 Documentation required for design review* ~~*1.2.12*~~ *1.2.14* is to be submitted for design review.

1.2.13 **Lithium battery systems.** In addition to the plans and information required by *Pt 16, Ch 1, 1.2 Documentation required for design review 1.2.2*, the following information is also to be submitted:

(a) System functional description including all operating modes (i.e. charging, discharging, standby, backup, peak shaving, etc.), safety functions and their hierarchy and expected battery system behaviour in case of malfunction.

(b) Technical description detailing how safety information from type testing has been considered in the actual installation design.

(c) Integration plan for the battery system with the vessel power distribution and charging arrangements.

(d) Line diagrams of the battery system control and power distribution, including switchgear, protective devices, controlgear and emergency trip (E-Trip) as well as interfaces to external systems.

(e) A Failure Mode and Effects Analysis (FMEA) and mitigation strategy is to be carried out for the lithium battery system installation as a whole in accordance with IEC 60812*: Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)*, or an equivalent and acceptable National or International Standard and the report and worksheets are to be submitted for consideration.

(f) Arrangement plans of any HVAC, ventilation, cooling system and drains for the battery space.

(g) Fire detection, alarm and extinguishing system (including portable fire-fighting appliances) plans for the battery space.

(h) A schedule of electrical equipment for use in the battery space and HVAC, ventilation and cooling system giving details of the appropriate type of protection for the temperature class and gas group of the potential gases. Copies of appropriate certification are to be submitted for consideration.

(i) Arrangement plans for electrical equipment showing cable routes associated with the battery system, power distribution and E-Trip.

(j) General arrangement plan showing hazardous zones for the battery space, including the HVAC, ventilation, cooling system and drains.

(k) Fire integrity plans for the battery space (including penetration drawings), contiguous spaces and means of escape from the battery space.

1.2.14 For ships with hybrid electrical power systems as detailed in *Pt 16, Ch 2, 23 Hybrid electrical power systems* the following documentation is to be submitted for design review either uniquely or integrated with other submitted information:

Information required for all hybrid electrical power systems:

(a) A functional description of the electrical distribution systems and equipment that details compliance with the performance criteria and system capability and functionality under defined normal and reasonably foreseeable abnormal conditions including:

   i. degraded modes of operation;
   ii. load management and load sharing philosophy;
   iii. earthing philosophy;
   iv. system electrical protection philosophy;
   v. system stability; and
   vi. converter switching actions.

(b) Definition of system performance targets (*see Pt 16, Ch 2, 23.5 Hybrid electrical power system performance - System performance targets*);

(c) Definition of dependability principles (*see Pt 16, Ch 2, 23.6 Hybrid electrical power system performance - Dependability principles*);

(d) Calculations supporting the size and rating of stores of electrical energy (*see Pt 16, Ch 2, 23.6 Hybrid electrical power system performance - Dependability principles 23.6.7*);

(e) Risk assessment in support of there being no dedicated emergency source of power when this is proposed (*see Pt 16, Ch 2, 23.8 Hybrid electrical power system performance - Emergency source of electrical power 23.8.2*);

(f) Details of any arrangements for external sources of power to charge onboard stores of electrical energy (see *Pt 16, Ch 2, 23.9 Hybrid electrical power system performance – External source of electrical power 23.9.3*);

(g) Voltage rate of rise times for pulse width modulated converters (see *Pt 16, Ch 2, 23.11 Hybrid electrical power system components - Source of electrical power 23.11.6*);

(h) Risk assessment in support of active fault current limiting devices when this is proposed (*see Pt 16, Ch 2, 23.15 Hybrid electrical power system components - Distribution system 23.15.11*);

(i) Technical description of energy management functionality (*see Pt 16, Ch 2, 23.16 Hybrid electrical power system components - Energy management 23.16.4* and *Pt 16, Ch 2, 23.16 Hybrid electrical power system components - Energy management 23.16.7*);

(j) Technical description of arrangements for power quality monitoring (*see Pt 16, Ch 2, 23.17 Transversal requirements 23.17.6*);

(k) Power system integration procedure (*see Pt 16, Ch 2, 23.18 Power system development and integration - General*);

(l) System operational concept (*see Pt 16, Ch 2, 23.19 Power system development and integration - System operational concept*);

(m) Technical description of operating modes (*see Pt 16, Ch 2, 23.20 Power system development and integration - Operating modes*);

(n) Validated specifications of system components (*see Pt 16, Ch 2, 23.22 Power system development and integration - System components*);

(o) Results of energy flow analysis (*see Pt 16, Ch 2, 23.23 Power system development and integration - Energy flows*);

(p) Results of power system analysis (*see Pt 16, Ch 2, 23.24 Power system development and integration - Power system analysis*);

(q) Definition of safety functions (*see Pt 16, Ch 2, 23.25 Power system development and integration - Safety functions*);

(r) System FMEA (*see Pt 16, Ch 2, 23.27 Power system development and integration - System Failure Modes and Effects Analysis (FMEA)*);
(s) System operating instructions (*see Pt 16, Ch 2, 23.28 Power system development and integration - Operating instructions*);
(t) Description and verification of ship-specific Operator training needs (*see Pt 16, Ch 2, Power system development and integration - Operator training 23.29*); and
(u) Description of through-life system integration roles and responsibilities (*see Pt 16, Ch 2, 23.30 Power system development and integration - Through-life accountability*).

Additional information required for Hybrid Power (+) notation systems:

(a) Dependability assessment (*see Pt 16, Ch 2, 23.6 Hybrid electrical power system performance - Dependability principles*);
(b) Technical description of arrangements for automatic earth fault location (*see Pt 16, Ch 2, 23.15 System components - Distribution system 23.15.16*);
(c) Technical description of arrangements for power quality degradation detection (*see Pt 16, Ch 2, 23.15 Transversal requirements 23.15.23*);
(d) Technical description of additional energy management functionality (*see Pt 16, Ch 2, 23.16 System components - Energy management 23.16.8*);
(e) Validation, verification and results of energy flow simulation (*see Pt 16, Ch 2, 23.23 Power system development and integration - Energy flows 23.23.3*);
(f) Validation, verification and results of power system simulation (*see Pt 16, Ch 2, 23.24 Power system development and integration - Power system analysis 23.24.4*);
(g) Risk assessment study when required (*see Pt 16, Ch 2, 23.26 Power system development and integration - Risk assessment*); and
(h) Evidence of ship-specific Operator training verification (*see Pt 16, Ch 2, 23.29.2 Power system development and integration - Operator training*).

1.3 Documentation required for supporting evidence

1.3.1 The documentation and particulars in *Pt 16, Ch 2, 1.3 Documentation required for supporting evidence 1.3.2* to *Pt 16, Ch 2, 1.3 Documentation required for supporting evidence ~~1.3.5~~ 1.3.7* are to be submitted as supporting evidence.

1.3.7 **Lithium battery systems.** In addition to the plans and information required by *Pt 16, Ch 2, 1.2 Documentation required for design review 1.2.13*, the following information is also to be submitted:

(a) Document outlining the operational limitations for the battery system.
(b) Operation, maintenance and training manuals for the battery system are to be kept on board including:
  (i) Manual that describes the standard operating, maintenance and emergency procedures for the system;
  (ii) Testing procedures including Annual Survey test requirements (*see Pt 16, Ch 2, 21 Testing and trials*, *Table 2.21.3 Test requirements on lithium battery systems*);
  (iii) Through-life management plan for the battery system, including disposal.

1.6 Definitions

1.6.17 A **‘**secondary lithium cell’ is a cell where electrical energy is derived from the insertion/extraction reactions of lithium ions or oxidation/reduction of lithium between the negative electrode and the positive electrode. These may be combined in ‘cell blocks’ consisting of a group of cells connected together in a parallel configuration.

1.6.18 A **‘**battery module’ is an energy storage device comprising one or more electrically connected cells or cell blocks. The battery module can include protective and monitoring devices.

1.6.19 A **‘**battery pack’ is an energy storage device comprising one or more electrically connected cells, cell blocks or modules. The battery pack can include protective devices and control and monitoring systems which communicate with the battery management system.

1.6.20 A ‘battery management system (BMS)’ is an electronic system which monitors and manages the state of a cell, battery module or battery pack in order to maintain the battery system in a safe operating state and protect against overcharging, overcurrent and overheating and communicates with an external charge/discharger controller.

1.6.21 A **‘**lithium battery system’ is a system comprising one or more lithium battery modules or packs incorporated in a fixed installation together with means of isolation, a cooling system (if provided) and has an associated BMS.

1.6.22 ‘State of charge (SOC)’ is the available capacity in a battery expressed as a percentage of rated capacity.

1.6.23 ‘State of health (SOH)’ reflects the general condition of a battery expressed as a percentage of its ability to deliver the specified performance compared with that of a new battery.

1.6.24 ‘Battery space’ is the space or compartment in which a battery is installed.

■ *Section 9*
Rotating machines

9.1 General requirements

9.1.1 ~~Rotating machines are to comply with the relevant part of IEC 60092: *Electrical installations in ships* or an acceptable and relevant National Standard, and the requirements of this Section.~~ In addition to the requirements of this Section, rotating machines are to comply with the relevant requirements of the following standards, amended where necessary for ambient temperature, *see Pt 16, Ch 2, 1.9 Ambient reference and operating conditions*:

(a) IEC 60034 *Rotating electrical machines* (all parts); and
(b) IEC 60092 *Electrical installations in ships* (all parts)*;* or
(c) an alternative International or National Standard acceptable to LR.

■ *Section 12*
Batteries

12.1 General

12.1.1 The requirements of this Section apply to aqueous and non-aqueous permanently installed secondary batteries of the vented and valve-regulated sealed type such that the following goal and functional requirements are achieved:

- **Goal**

  Safe energy storage and dependable supply of power to consumers.
- **Functional requirements**

  Reasonably foreseeable hazards external to the battery shall be identified and managed.

  Reasonably foreseeable hazards internal within the battery shall be identified and managed.

12.1.4 The following Sections apply to lead acid, ~~and~~ nickel cadmium and lithium cell chemistries. Where other chemistries are to be used, the LR ~~ShipRight Procedure~~ *ShipRight Procedure* *Assessment of Risk Based Designs* is to be followed.

12.1.5 Lithium battery systems are to satisfy the requirements of LR’s *Type Approval System Test Specification Number 5 (2019)*. Alternative arrangements may be subject to special consideration.

12.1.6 Lithium battery management systems are to satisfy the requirements of LR’s *Type Approval System Test Specification Number 1 (2018)*. Alternative arrangements may be subject to special consideration.

12.1.7 Where the lithium battery total system installation is less than 20 kWh then it is to be housed in a gastight steel enclosure with a gastight ventilation duct leading to a safe space on open deck and is to be suitable for withstanding the temperatures and pressures generated in the worst case thermal runaway condition. The battery system is to satisfy the requirements of LR’s *Type Approval System Test Specification Number 5 (2019)*, or an equivalent and acceptable National or International Standard, amended where necessary for a battery space ambient temperature of 45°C. Alternative arrangements will be subject to special consideration.

12.1.8 The following Sections apply to lithium battery system installations of a total system capacity of 20 kWh or greater and are in addition to those applicable in other Parts of these Rules:

- *Pt 16, Ch 2, 12.1 General 12.1.9*;
- *Pt 16, Ch 2, 12.2 Design and construction 2.2.2* to *Pt 16, Ch 2, 12.2 Design and construction 12.2.6*;
- *Pt 16, Ch 2, 12.3 Location 12.3.12*;
- *Pt 16, Ch 2, 12.4 Installation 12.4.6* to *Pt 16, Ch 2, 12.4 Installation 12.4.10*;
- *Pt 16, Ch 2, 12.5 Thermal management and ventilation 12.5.8* and *Pt 16, Ch 2, 12.5 Thermal management and ventilation 12.5.12*;
- *Pt 16, Ch 2, 21.1 Testing 21.1.6.*

12.1.9 For lithium battery system installations of nominal voltages exceeding 1500 V d.c. the LR *ShipRight Procedure Assessment of Risk Based Designs* is to be followed.

12.1.10 Additional requirements may be imposed by the National Administration with which the ship is registered and/or by the Administration within whose territorial jurisdiction the ship is intended to operate. Where any such requirements exist, in the event of a conflict with the requirements herein the requirements of the National Administration will generally take precedence.

12.1.11 Integration of a lithium battery system that satisfies a ship’s main power demand into the ship’s electrical power system is to be in accordance with Pt 16, Ch 2, 23 Hybrid electrical power systems

12.2 Design and c~~C~~onstruction

12.2.2 A Failure Mode and Effects Analysis (FMEA) is to be carried out for the lithium battery system installation and is to consider the effects of failure upon safety and dependability of the lithium battery system installation taking account of reasonably foreseeable internal and external failures such that the goal and functional requirements of *Pt 16, Ch 2, 12.1 General 12.1.1* are achieved and is to include but not limited to the following:

(a) overpressure, fire and explosion;
(b) electrical short circuit due to leakage of cell electrolyte or mechanical impact;
(c) venting out flammable and toxic gases;
(d) rupture of the casing of cell, battery module, battery pack or battery system with exposure of internal components; and
(e) ingress of water into the battery space from cooling system leak, fire suppression system release and/or adjacent areas.

No single failure is to directly result in conditions more arduous than those under which the battery system has been type tested or in the hidden loss of any monitoring and control, alarm or safety function (either automatic or manual) on which the battery system installation depends for its safe operation.

12.2.3 The casing of a lithium cells and/or battery modules is to incorporate a pressure relief function(s) that will prevent overpressure, rupture or explosion of the battery module enclosure (*see Pt 16, Ch 2, 21 Testing and trials*).

12.2.4 The lithium battery management system is to continuously monitor the condition of cells, battery modules or battery packs and to maintain them within their specified safe operating region. As a minimum the alarms and safeguards as indicated in *Table 2.12.1 Lithium battery system: alarms and safeguards* are to be provided:

Table 2.12.1 Lithium battery system: alarms and safeguards

Item	Alarm	Note
Cell voltage*	High	Automatic termination of the cell charge current. *See* Notes 1 and 5
	Low	Per cell. Automatic prevention of cell discharge. *See* Notes 2 and 5
Cell temperature*	1st stage high	Per sensor. *See* Notes 4 and 5
	2nd stage high	Per sensor. Automatic shutdown of battery system. *See* Notes 4 and 5
	Low	Automatic charge and discharge current limitation. *See* Notes 3 and 4
Charge current of the battery cells	High	Automatic reduction of charge/discharge current. *See* Note 3
Communication failure between battery management system and external charge controller system	Failure	Automatic shutdown of battery system *See* Note 6
Battery management system	Failure	Automatic shutdown of battery system
Temperature sensor	Failure	Automatic shutdown of battery system
Voltage sensor	Failure	Automatic shutdown of battery system
Emergency trip*	Active	Automatic shutdown of battery system *See* Note 5
Insulation resistance	Low	-
Note 1. Cell voltage is to be maintained below the cell manufacturer specified upper limit charge voltage.		
Note 2. Cell voltage is to be maintained above the cell manufacturer specified lower limit discharge voltage.		
Note 3. Cell charge/discharge current is to be controlled within cell manufacturer specified current limits.		
Note 4. Cell temperature is to be controlled within the cell manufacturer specified temperature limits.		
Note 5. For lithium batteries used as an emergency source of power, only items marked * are to initiate automatic shutdown.		
Note 6. For lithium batteries used as an emergency source of power, communication failure is to automatically stop and prevent charging.		
Note 6. Automatic shutdown of battery system includes termination of battery charging and discharging and disconnection from electrical distribution network.		

12.2.5 A fully independent hard-wired means to disconnect the battery system in an emergency from power distribution is to be provided. This emergency trip is to be located outside of the battery space and situated such that it will remain accessible in the event of an emergency inside the battery space and is to initiate an audible and visual alarm at the relevant control stations to advise duty personnel of the emergency condition.

12.2.6 For lithium battery system installations the following is to be measured and displayed at control stations relevant to the system in which the battery system is installed:

(a) State of charge (SOC) and state of health (SOH) are to be displayed at relevant control stations and on the navigating bridge.
(b) System alarms are to be displayed at relevant control stations and at least a common alarm displayed on the navigating bridge.

12.3 Location

12.3.12 The lithium battery space is to be separate from other spaces and compartments and not to be located forward of the collision bulkhead and is not to be contiguous to the boundaries of machinery spaces of Category A or those spaces containing the main source of electrical power, associated transforming equipment (if any) or the main switchboard. The boundaries of the lithium battery space are to be part of a vessel structure or enclosures and provided with ‘A-60’ insulation of the bulkhead unless the space is adjacent to spaces of negligible fire risk such as cofferdams, void spaces or similar, in which case consideration may be given to reducing the insulation to ‘A-0’. Penetrations through these boundaries are to be protected to the same fire protection standard. Special consideration will be made for a ship not built of steel or equivalent material. All other safety systems within the lithium battery spaces are to be in accordance with the requirements of this Section or, if not made explicit, at least equivalent to those of a machinery space of Category A.

12.4 Installation

12.4.5 High speed craft are to be provided with an alarm to indicate that immediate action is required in the event of thermal runaway of any nickel cadmium or lithium battery system.

12.4.6 Battery systems are to be installed in accordance with manufacturer’s recommendations taking account of the results of the FMEA study.

12.4.7 The lithium battery space and the crates, trays, boxes, shelves and other structural parts therein are to be designed and constructed such that the structural integrity of the battery space will not be compromised in the event of a lithium fire.

12.4.8 The lithium battery space is to be fitted with suitable fixed detectors in accordance with manufacturer’s recommendations which are capable of providing early identification of a fire or thermal runaway condition. Early identification is to include high cell temperature or detection of electrolyte solvent vapours and a combination of smoke and heat detectors. When activated, the fire detection system is to initiate an alarm to the relevant control stations and on the navigating bridge and is to initiate the automatic isolation of electric systems within the lithium battery space except as described below, and activate the fixed fire-fighting system.

12.4.9 In the event that a fire or thermal runaway condition is identified, the battery monitoring system is to initiate protective features such as automatic safe isolation of the batteries. Ventilation necessary for extraction of gases, active cooling systems, and thermal/safety monitoring and alarm are to be continued prior to, during and after an overheating or fire event. Failure of the monitoring system is to be alarmed to the ship’s safety system and is to result in the battery system automatically reverting to a defined safe state.

12.4.10 An appropriate water-based fixed fire-fighting system in accordance with SOLAS II-2, Part C, Regulation 10.4.1.1.3 and the manufacturer’s recommendation is to be provided for the lithium battery space. The fixed fire-fighting system is to be suitable for heat removal, boundary cooling and/or extinguishment for the duration that the heat and/or gas release is present. Fixed fire-fighting systems using a medium other than water which provide equivalent heat removal, boundary cooling and/or extinguishment for the duration that the heat and/or gas release is present can be taken into consideration provided that appropriate fire tests have been conducted. In particular, the fire-extinguishing media are to be chosen as appropriate for the specific type and characteristics of fire foreseen.

12.4.11 The fixed fire-fighting control system is to be located outside the battery space, be activated automatically and capable of manual activation. In addition to the fixed fire-fighting system, the battery space is to be provided with a minimum of two (2) portable and suitable fire-extinguishers located outside the space at or near the entrance(s). The number and position of hydrants are to be such that at least two jets of water not emanating from the same hydrant, each from a single length of hose, can reach any part of the lithium battery space. Such hydrants are to be positioned in close proximity to the lithium battery space. Any part of the fire-fighting system which crosses through the lithium battery space without serving it, is to be avoided.

12.4.12 The fire detection and alarm systems are to be in accordance with the recommendations of the battery manufacturer and the following sub-Sections of these Rules:

- *Pt 16, Ch 1, 2.8 Fire detection alarm systems*;
- *Pt 16, Ch 2, 17.1 Fire detection and alarm systems*;

12.4.13 The technical description detailed in *Pt 16, Ch 2, 1.2 Documentation required for design review 1.2.13(b)* is to consider the actual battery system installation and its integration into the ship, including but not limited to the following:

- arrangement of battery compartment (location, including fire risk of adjacent spaces/compartments, fire burden from equipment other than batteries, heat sources, etc.);
- temperature control arrangements for the battery space and their contribution to system safety;
- ventilation arrangements to prevent concentrations of gasses within the space in case of uncontrolled thermal runaway
- hazardous area(s) requirements;
- reasonable gas tightness of ventilation ducting;
- fire integrity of the space;
- the use of fire extinguishing arrangements for cooling in the case of uncontrolled thermal runaway.

The FMEA referenced in *Pt 16, Ch 2, 12.2 Design and construction 12.2.2* should address any additional failure modes identified during the preparation of this technical description.

12.4.14 The lithium battery space is to be provided with two means of escape, at least one independent of any watertight door and leading to a safe position outside the space. One of the escapes is to be suitable for the passage of a stretcher. At each entrance/exit an emergency escape breathing device (EEBD) is to be provided. Where the maximum travel distance to the door within the lithium battery space is less than 5 m, a single means of escape is acceptable. The lithium battery space is not to be considered as part of an escape route (primary or secondary) from any other accommodation, control, service space, machinery space of Category ‘A’ and high fire risk area such as a garage, paint store, etc.

12.5 Thermal management and v~~V~~entilation

12.5.8 Ventilating fans for battery compartments are to be so constructed and be of material such as to minimise risk of sparking in the event of the impeller touching the casing, and are to be suitable for the potentially hazardous and corrosive gases produced in a thermal runaway condition. Non-metallic~~,~~ impellers are to be of an anti-static material.

12.5.12 Thermal management of the lithium battery space is to be assessed, including the criticality of any cooling systems required to ensure reliable operation and to prevent thermal runaway within the marine environment. *See also Pt 16, Ch 1, 1.3 Control, alarm and safety equipment 1.3.3*.

■ *Section 17*
Fire safety systems

17.1 Fire detection and fire alarm systems

17.1.1 Fire detection and fire alarm systems are to be in accordance with *Chapter 9 – Fixed fire detection and fire alarm systems* of the ~~Fire Safety Systems Code (~~FSS Code~~)~~ and ~~*Pt 16, Ch 2, 17.1 Fire detection and alarm systems 17.1.2*~~ the requirements in this Section as applicable.

17.1.8 For ~~ships~~ a craft other than passenger ~~ships~~ a craft where the fire detection system does not include means of remotely identifying each detector and manually operated call point individually, no section covering more than one deck within accommodation, service spaces and control stations is normally to be permitted except a section which covers an enclosed stairway. The number of enclosed spaces in each section is to be limited to the minimum considered necessary in order to avoid delay in identifying the source of fire. In no case are more than 50 spaces permitted in any section.

17.2 Automatic ~~sprinkler system~~ sprinkler, fire detection and fire alarm systems

17.3 Fixed water-based local application fire-fighting systems

17.3.5 For the electrical safety of electrical and electronic equipment in areas protected by fixed water-based local application, fire-fighting systems and adjacent areas where water may extend, the requirements of *Pt 16, Ch 2, 17.3 Fixed water-based local application fire-fighting systems 17.3.6* to *Pt 16, Ch 2, 17.3 Fixed water-based local application fire-fighting systems 17.3.10* apply.

17.3.11 Fixed water-based local application fire-fighting system electrically-driven pumps may be shared with:

- equivalent automatic sprinkler systems;
- equivalent main machinery space fire-fighting systems; or
- local fire-fighting systems for deep-fat cooking equipment;

provided that the shared use is accepted by the National Administration as complying with applicable ~~s~~Statutory ~~r~~Regulations and the arrangements comply with the requirements of *Pt 16, Ch 2, 17.3 Fixed water-based local application fire-fighting systems 17.3.12* to *Pt 16, Ch 2, 17.3 Fixed water-based local application fire-fighting systems 17.3.14*.

17.5 ~~Refrigerated liquid carbon dioxide systems~~ Fixed gas fire-extinguishing systems

17.5.3 Where it is required that alarms be provided to warn of the release of a fire-extinguishing medium, and these are electrically operated;

- they are to be provided with an emergency source of electrical power, as required by;
  - *Pt 16, Ch 2, 3.2 Emergency source of electrical power in passenger craft and for yachts that are 500 gt or more* or;
  - *Pt 16, Ch 2, 3.3 Emergency source of electrical power in craft required to comply with the HSC Code* or;
  - *Pt 16, Ch 2, 3.4 Emergency source of electrical power in cargo craft, patrol and pilot craft, workboats and other similar craft of 500 tons gross tonnage and above; and cargo craft, patrol and pilot craft, workboats and other similar craft less than 500 tons gross tonnage for operation in Service Groups 4 to 6*;
- also connected to the main source of electrical power, with automatic changeover facilities located in, or adjacent to, the fire-extinguishing media release panel, *see also Pt 16, Ch 2, 1.15 Alarms;* and
- Failure of any power supply is to operate an audible and visual alarm, *see also Pt 16, Ch 2, 1.15 Alarms* and *Pt 16, Ch 2, 1.16 Operation under fire conditions*.

17.8 Fire dampers

17.8.1 The electrical power required for the control and indication circuits of fire dampers is to be supplied from the emergency source of electrical power, *see also Pt 16, Ch 2, 1.16 Operation under fire conditions*.

Existing sub-Section 17.9 has been deleted.

Existing sub-Section 17.10 has been renumbered 17.9.

■ *Section 21*
Testing and trials

21.1 Testing

21.1.6 Tests at the manufacturers' works and after installation on board are to include such tests necessary to demonstrate, to the Surveyor's satisfaction, the suitability and safety of the lithium battery system for its intended duty and location. As a minimum, the tests listed in *Table 2.21.3 Test requirements on lithium battery systems* are required.

Table 2.21.3 Test requirements on lithium battery systems

Item	Tests	Trials
Discharge performance validation	X	
Capacity validation test *	X	X
Internal d.c. resistance test	X	
Overcharge control test	X	
Cell balancing functional test	X	
Sensor failures test	X	
SOC validation test *	X	X
SOH validation test *	X	X
High voltage test	X	
Insulation resistance test	X	
Emergency trip functional test *	X	X
Over-temperature protection test	X	X
Over-voltage protection test	X	X
Under-voltage protection test	X	X
Communication failure between BMS and external charge control system test *	X	X
Pressure relief valve test	X	
Additional safety functions tests and trials of the battery management system	X	X
Note Items marked * are required to be tested annually.		

■ *Section 23*
Hybrid electrical power systems

23.1 Scope

23.1.1 The requirements of this Section are applicable to ships having a main source of electrical power which is provided by hybrid electrical power generation and distribution systems within which the main electrical power demand is supplied by two or more different types of power source or by stored electrical energy.

23.1.2 These requirements apply to the design, construction and integration of hybrid electrical power systems, their sub-systems, machinery and equipment.

23.1.3 These requirements apply to hybrid electrical power systems which provide the main source of electrical power and exceptionally, where permitted by the National Administration, the emergency source of electrical power.

23.1.4 In addition to these requirements National Administrations may impose further requirements. Where such requirements conflict with these requirements, the requirements of the National Administration will take precedence.

23.1.5 These requirements are additional to the applicable requirements of the *Rules and Regulations for the Classification of Special Service Craft, July 2019*.

23.2 Characters of classification and class notations (machinery special features)

23.2.1 Ships complying with the mandatory requirements of this Section will be assigned the **Hybrid Power** machinery special features notation.

23.2.2 Ships complying with both the mandatory requirements and the additional optional requirements of this Section will be assigned the **Hybrid Power (+)** machinery special features notation.

23.2.3 **Hybrid Power**: Assigned to ships with an electrical power system including a combination of two or more different types of power source or utilising stored electrical energy to satisfy the ship’s main power demand. The system and its component parts are in accordance with the existing applicable requirements of the Rules and the requirements of *Pt 16, Ch 2, 23 Hybrid electrical power systems*.

23.2.4 **Hybrid Power (+)**: Assigned to ships meeting the requirements for **Hybrid Power** and the additional optional requirements for **Hybrid Power (+)** specified within *Pt 16, Ch 2, 23 Hybrid electrical power systems*. The additional optional requirements aim to provide for enhanced performance of the electrical power system achieved through the consideration of system simulation, system integration and the dependability of the electrical power system during normal or reasonably foreseeable abnormal operation.

23.3 Definitions

23.3.1 Hybrid electrical power system: A ship’s electrical power system comprising sources, stores, consumers and distribution of electrical power together with their associated controls within which electrical power is provided by two or more different types of power source or utilising stored electrical energy to satisfy the ship’s main power demand. This definition is independent of:
(a) the type of distribution system (*see Pt 16, Ch 2, 23.3 Definitions 23.3.8*);
(b) the types and ratings of source, their physical location and time duration of connection to the ship’s power system;
(c) the types of store;
(d) the types of connected consumer; and
(e) the presence or otherwise of electric propulsion.

23.3.2 Reasonably foreseeable abnormal condition: A reasonably foreseeable abnormal condition is an operation, event, incident or failure that:
(a) has happened and could happen again;
(b) has not happened but is considered possible. Where the likelihood is considered extremely unlikely or the consequences are trivial, and no further prevention or mitigation action is to be taken, then this is to be justified; and
(c) is planned for (e.g. emergency actions cover such a situation, maintenance is undertaken to prevent it, etc.).

They should be identified by:
(a) using analysis processes that are capable of revealing abnormal conditions;
(b) employing a mix of personnel including designers, Operators, persons who carry out maintenance and competent safety/risk professionals with relevant domain knowledge and understanding to apply the processes;
(c) referencing relevant events and historic data; and
(d) documenting the results of the analysis.

23.3.3 Source of electrical power: A source of electrical power produces electrical power from an energy source such that its output may be connected to ship’s electrical power distribution system (*see Figure 2.23.1 Source of electrical power*). It includes:
(a) Dedicated conversion where conversion is the changing of an output with respect to its input and may include change of form (e.g. a.c. to d.c. or d.c. to a.c.), change in magnitude (e.g. of voltage, current or frequency), change in phase or change in reference (e.g. through galvanic isolation);
(b) Management systems perform monitoring, control, protection and safety functions that are likely to be connected to higher level ship wide supervisory systems; and
(c) Systems providing control, alarm, monitoring and safety functions such as control panel, governor, automatic voltage regulator (AVR) and emergency shutdown (ESD) system for a reciprocating engine or gas turbine generator.

This definition of source of electrical power is independent of:
(a) the type of source (e.g. rotating generator, waste heat recovery system, wind generator, solar panel, fuel cell, photovoltaic array);
(b) the type of distribution system (*see Pt 16, Ch 2, 23.3 Definitions 23.3.8*); and
(c) the application of the source (e.g. main/additional/emergency/transitional source of power).

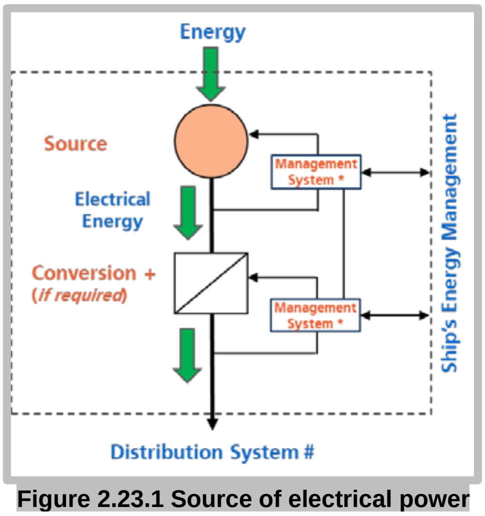


Figure 2.23.1 Source of electrical power

23.3.4 Additional source of electrical power: An additional source of power is a source of electrical power not forming part of the ship's main source of power that is rated to supply any proportion of the ship's main power demand at any time either continuously or for an accepted period of time, e.g. an energy storage device or a power take-off that is not rated for or capable of permanent operation.

23.3.5 Store of electrical energy: A store of electrical energy receives, stores and discharges energy through a single point of common coupling with the distribution system (*see Figure 2.23.2 Store of electrical energy*). It includes management systems and any required dedicated conversion as defined in *Pt 16, Ch 2, 23.3 Definitions 23.3.4*.3. This definition is independent of:
(a) the method of energy storage;
(b) the type of store (e.g. battery, capacitor);
(c) the type of distribution system (*see Pt 16, Ch 2, 23.3 Definitions 23.3.8*); and
(d) the application of the store (e.g. power source, load smoothing, peak shaving, dynamic response, power backup).

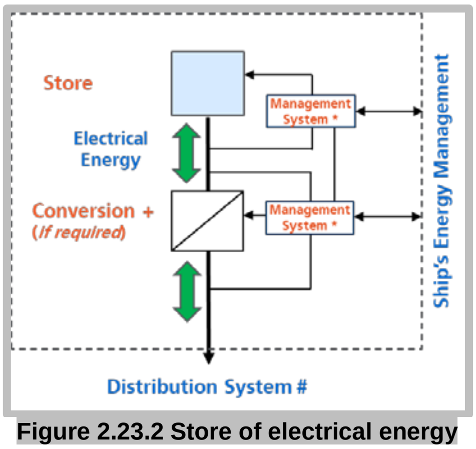


Figure 2.23.2 Store of electrical energy

23.3.6 Consumer of electrical power: A consumer of electrical power takes its input from the electrical distribution system and delivers useful work through its associated load (*see Figure 2.23.3 Consumer of electrical energy*). It includes management systems and any required dedicated conversion as defined in *Pt 16, Ch 2, 23.3 Definitions 23.3.3*. Consumers are present in any electrical power system and are not unique to hybrid electrical power systems. The definition is provided here for completeness.

This definition is independent of:
(a) the type of load or the purpose for which it is installed; and
(b) the type or physical form of distribution system.

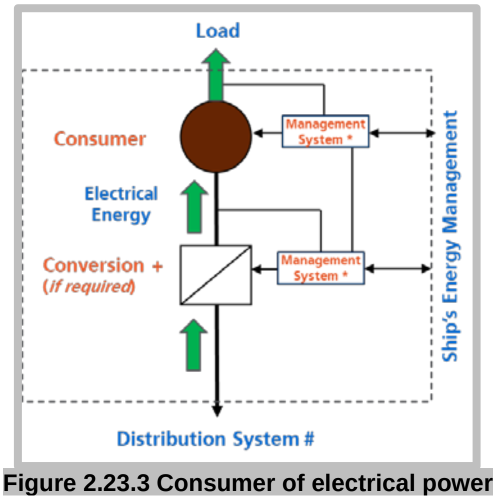


Figure 2.23.3 Consumer of electrical power

23.3.7 Combined sources/stores/consumers of electrical power: A combined source/store/consumer of electrical power provides multiple functions as defined in *Pt 16, Ch 2, 23.3 Definitions 23.3.3* to *Pt 16, Ch 2, 23.3 Definitions 23.3.6* in a single functional arrangement (some examples are shown in *Figure 2.23.4 Combined source and consumer of electrical power* to *Figure 2.23.7 Combined store of electrical energy and source and consumer of electrical power*). They include management systems and any required dedicated conversion as defined in *Pt 16, Ch 2, Definitions 23.3.3*.

Figure 2.23.4 Combined source and consumer of electrical power to *Figure 2.23.7 Combined store of electrical energy and source and consumer of electrical power* depict building blocks that may be encountered in a hybrid electrical power system. These do not represent complete systems, are provided for illustration purposes only and are not exhaustive with further permutations being viable.

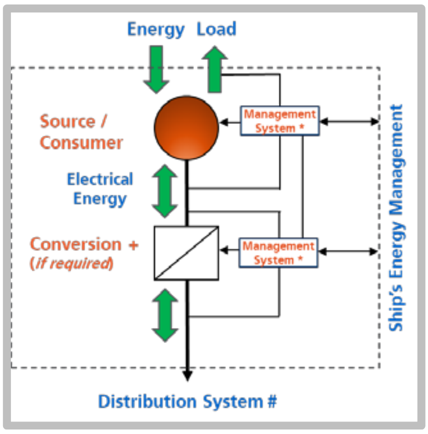


Figure 2.23.4 Combined source and consumer of electrical power

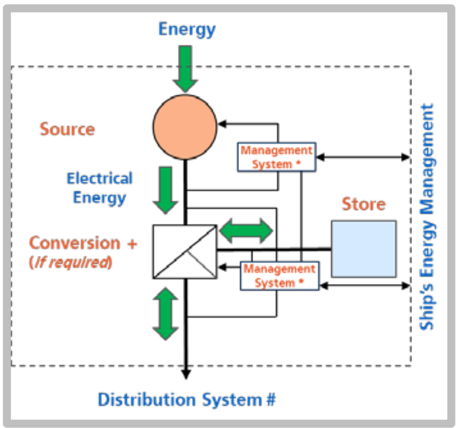


Figure 2.23.5 Combined source of electrical power and store of electrical energy

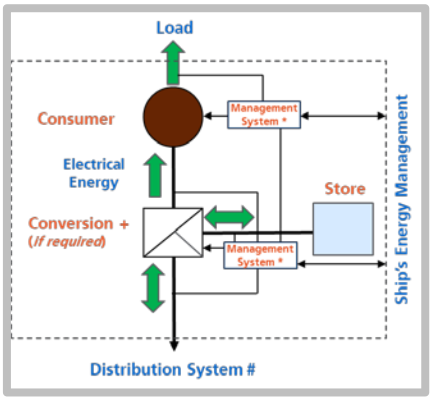


Figure 2.23.6 Combined store of electrical energy and consumer of electrical power

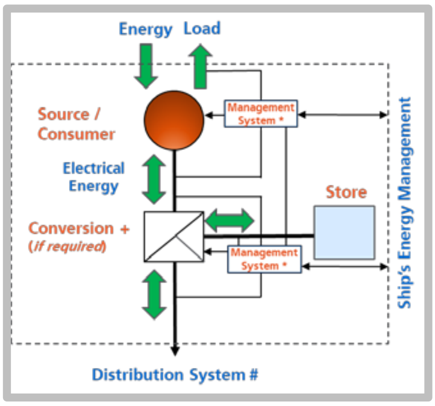


Figure 2.23.7 Combined store of electrical energy and source and consumer of electrical power

23.3.8 Distribution system: The distribution system provides the interconnection between, protection of and isolation of:

- sources (*see Pt 16, Ch 2, 23.3 Definitions 23.3.3* and *Pt 16, Ch 2, 23.3 Definitions 23.3.4*);
- stores (*see Pt 16, Ch 2, 23.3 Definitions 23.3.5*);
- consumers (*see Pt 16, Ch 2, 23.3 Definitions 23.3.6*); and
- combinations thereof (*see Pt 16, Ch 2, 23.3 Definitions 23.3.7*).

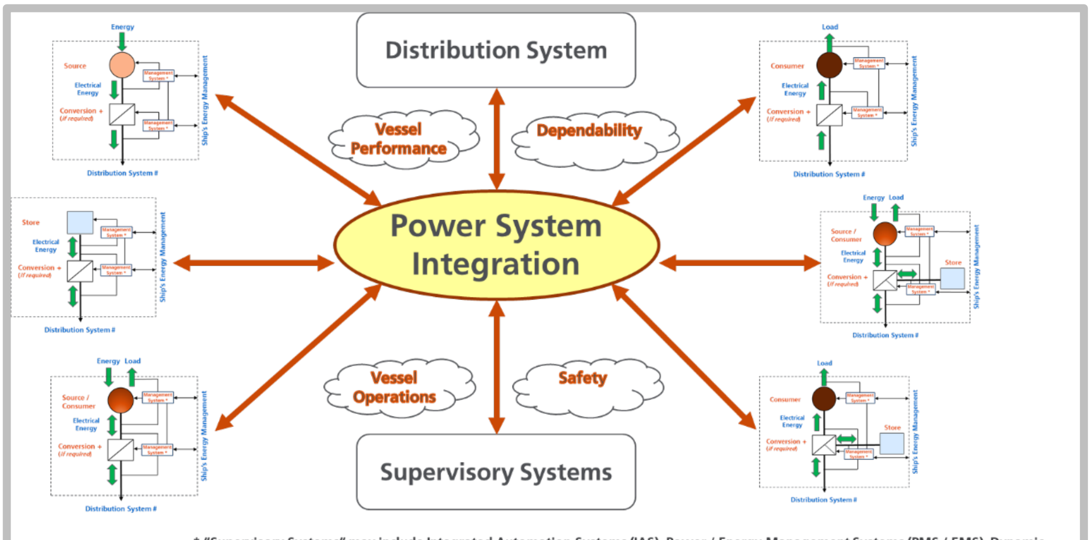
It includes management systems (e.g. power management) and any required dedicated conversion as described in *Pt 16, Ch 2, 23.3 Definitions 23.3.4*. There are no constraints on its type (e.g. a.c. or d.c.), magnitude (e.g. voltage and/or frequency), nature (e.g. fixed or variable), architecture (e.g. tree, radial, zonal), physical form or on the number of variants within a ship.

23.3.9 Energy management: Energy management functionality provides the overall control, monitoring, protection and safety functions that are necessary to deliver dependable electrical power from the hybrid electrical power system in all operating modes and under both normal and reasonably foreseeable abnormal conditions. It comprises supervisory functions that integrate the management systems of the components (sources, stores, consumers, distribution systems) from which the hybrid system is constructed and may be implemented as a stand-alone system or as distributed functionality across a number of systems.

Energy management is focused on energy flow and is typically model based, predictive in nature, inclusive of optimisation functionality and employing the principles of health and condition monitoring at system level (e.g. as described in *ShipRight Procedure for the Approval of Digital Health Management Systems*).

Energy management functionality is considered additional to the functionality of a conventional power management system as described in IEC 60092-504, *Electrical installations in ships, Part 504: Automation, control and instrumentation,* Section 9.4*.*

23.3.10 Power system integration: Power system integration comprises those system level activities that are required to be undertaken to design and develop, build and then operate and maintain safely through life a dependable ship's hybrid electrical power system including its constituent components (shown pictorially in *Figure 2.23.8 Role of system integration activities*). At each phase of a project power system integration is managed by a single designated party and is carried out in accordance with a defined procedure identifying the roles, responsibilities and requirements for all parties involved.



* "Supervisory Systems" may include Integrated Automation Systems (IAS), Power / Energy Management Systems (PMS / EMS), Dynamic Positioning (DP) Control Systems, Health / Condition Monitoring Systems, ….. etc.

Figure 2.23.8 Role of system integration activities

23.3.11 Dependability: Dependability is as defined in IEC 60050(191), *Quality vocabulary – Part 3: Availability, reliability and maintainability terms – Section 3.2: Glossary of international terms*. It is the collective term used to describe the availability performance and its influencing factors: reliability performance, maintainability performance and maintenance support performance as agreed with LR.

23.4 Hybrid electrical power system performance - System functional requirements

23.4.1 To provide sufficient electrical power of appropriate dependability to supply the required essential services, habitability requirements and those services required to maintain the ship in a normal sea-going and operational state during defined operational conditions without recourse to the emergency electrical supply.

23.4.2 Damage and injury: To provide electrical systems and equipment with suitable protection under fault conditions to prevent the following:
(a) injury to onboard personnel;
(b) damage to the equipment itself; and
(c) damage to equipment connected to it.

23.4.3 On ships with electric propulsion, to provide sufficient electrical power necessary for an effective and agreed level of propulsion power during all normal and reasonably foreseeable abnormal operational conditions.

23.5 Hybrid electrical power system performance - System performance targets

23.5.1 For **Hybrid Power** notation the performance of the system is to be such that in the event of a single failure operation of the system may be interrupted but is to be recoverable to a defined state bounded by time and magnitude.

23.5.2 For **Hybrid Power (+)** notation the performance of the system is to be such that in the event of a single failure operation of the system is to be uninterrupted with any degradation of performance agreed between the designers and Owners.

23.5.3 The hybrid electrical power system performance targets in all modes of operation are to be defined and agreed between the designers and Owners.

23.5.4 The electrical system design maximum and minimum operating voltage and input frequency together with acceptable limits of excursions are to be specified by the system designer and are to be in compliance with the requirements of the Rules.

23.5.5 Specific consideration is to be given to time-based performance targets for systems in which stored electrical energy supplies any part of the ship's main power demand.

23.5.6 Methods of verification of actual performance against targets are to be defined and are to cover all phases of the lifecycle.

23.6 Hybrid electrical power system performance - Dependability principles

23.6.1 The hybrid electrical power system dependability principles are to be defined and agreed between the designers and Owners consistent with the requirements for **Hybrid Power** or **Hybrid Power (+)** notation.

23.6.2 The principles are to cover defined operating modes, all normal and reasonably foreseeable abnormal operating and fault conditions and are to specifically consider the fault ride-through capability of the system.

23.6.3 The principles are to cover failures in active components of any of the sources, stores, consumers, distribution system and energy management forming the hybrid electrical power system. Such components may include, but are not restricted to, the following:

(a) prime movers (e.g. auxiliary engines);
(b) generators and their excitation equipment;
(c) gearing;
(d) pumps;
(e) fans;
(f) switchgear and controlgear, including their assemblies;
(g) thrusters; and
(h) valves (where power actuated).

23.6.4 Consideration is to be given to other enabling systems not part of the hybrid electrical power system whose failure or degradation could affect correct functioning of the hybrid electrical power system (e.g. lubrication, cooling and ventilation systems).

23.6.5 The continuity of supply to essential and emergency safety systems is to be maintained, in accordance with *Pt 16, Ch 2, 2 Main source of electrical power*.

23.6.6 Arrangements are to ensure that the supply of essential services is not disrupted by the unavailability of the largest source of electrical power and are to be in accordance with a clearly described, documented and agreed redundancy design intent.

23.6.7 The size and rating of electrical energy stores is to be appropriate for the specified lifetime when subjected to in-service cyclic loading. Calculations supporting this assessment are to be provided to LR.

23.6.8 For **Hybrid Power (+)** notation, a hybrid electrical power system dependability assessment is to be undertaken and submitted to LR. The objectives of the assessment are to:
(d) demonstrate the dependability of the system during all normal and reasonably foreseeable abnormal conditions; and
(e) demonstrate that an appropriate level of dependability is achieved that is commensurate with that agreed between the designers and Owners.

The assessment shall be undertaken to a recognised standard that is acceptable to LR (e.g. IEC 60300-3-1*, Dependability management Part 3-1: Application guide – Analysis techniques for dependability – Guide on methodology*).

23.7 Hybrid electrical power system performance - Main source of electrical power

23.7.1 The main source of electrical power is to comply with the requirements of *Pt 16, Ch 2, 2 Main source of electrical power*.

23.7.2 Any type of source of electrical power as detailed in these hybrid electrical power system Rules may, subject to the approval of LR, be considered as having equivalent function of that of a generating set as described in the *Rules and Regulations for the Classification of Special Service Craft, July 2019* including, but not limited to, *Pt 16, Ch 2, 2 Main source of electrical power*.

23.7.3 Sources of electrical power not forming part of the ship's main source of electrical power may be used as an additional source of electrical power to supply electrical services required for normal operational and habitable conditions provided that:
(a) The quality of power supplies meets the requirements of *Pt 16, Ch 2, 23.17 Transversal requirements 23.17.3*; and
(b) Automatic arrangements are provided to start and connect within a period not exceeding 45 seconds one of the sources forming the main source of electrical power in the event of a single failure or the quality of power supplies exceeding limits.

23.8 Hybrid electrical power system performance - Emergency source of electrical power

23.8.1 The emergency source of electrical power is to comply with the requirements of *Pt 16, Ch 2, 3 Emergency source of electrical power*.

23.8.2 For ships with a specified service notation as defined in *Pt 1, Ch 2, 3.3 Class notations (hull)*, where it is proposed that a dedicated emergency source of electrical power and its associated transitional source of power will not be provided, the main source of electrical power and associated equipment is to meet the following requirements:
(a) Sources providing the main source of electrical power are to be:
    i. separated and located in two or more compartments that are not contiguous with each other;
    ii. self-contained and arranged to be independent such that each system can operate without recourse to the other main source(s) including power distribution and any associated auxiliary and ancillary converting equipment and control systems;
    iii. arranged such that a fire, flood or casualty in any one of the compartments will not affect the electrical power distribution from the other(s), or to the services required by *Pt 16, Ch 2, 3 Emergency source of electrical power*;
    iv. capable of being started automatically on loss of the power supplied by the other main source(s) of electrical power and supplying the essential services as quickly as is safe and practicable subject to a maximum of 45 seconds, or provided with a transitional source of emergency electrical power;
    v. arranged to allow for maintenance at sea of any one source without affecting the ability to comply with these requirements; and
    vi. provided with starting arrangements compliant with the requirements of *Pt 10, Ch 1, 9.5 Starting of the emergency source of power.*
(b) Where these Rules specify that a service is required to be connected to both the main and emergency source of electrical power or is to be connected to the emergency switchboard, then these services are to be served by at least two individual circuits from the separated main sources of electrical power with arrangements to transfer between the two sources. The supplies are to be separated in their switchboard and throughout their length as widely as is practicable without the use of common feeders, protective devices, control circuits or controlgear assemblies so that any single fault will not cause the loss of both supplies.

(c) Provision is to be made for periodic testing to demonstrate services required by *Pt 16, Ch 2, 3 Emergency source of electrical power* can be supplied automatically following the loss of one main source of electrical power.

(d) To demonstrate compliance with these requirements a risk assessment of the electrical, mechanical, piping arrangements, cooling arrangements and any other sub-systems whose failure or degradation could have an impact on the performance of the system is to be carried out demonstrating that a single point failure such as a fire or flooding within a space would not render the systems incapable of supplying those services required in an emergency or other reasonably foreseeable abnormal event. The assessment is to be undertaken to a recognised standard that is acceptable to LR (e.g. ISO 31010, *Risk management – Risk assessment techniques*) and in accordance with *ShipRight Procedure Assessment of Risk Based Designs* and associated annexes.

23.9 Hybrid electrical power system performance - External source of electrical power

23.9.1 Ships utilising an external source of power are to comply with the requirements of *Pt 16, Ch 2, 4 External source of electrical power*.

23.9.2 Arrangements for d.c. external sources are to comply with a recognised standard that is acceptable to LR.

23.9.3 An external source of power may be used to charge onboard stores of electrical energy. Details of any such arrangements and their interfaces to ship systems are to be provided for consideration by LR.

23.10 Hybrid electrical power system performance - Electrical power supply to ship propulsion and ship positioning systems

23.10.1 Ships with electric propulsion are to comply with the relevant power requirements of *Pt 16, Ch 2, 16.1 Electric propulsion*.

23.10.2 Ships with electrically driven azimuthing thrusters are to comply with the relevant power requirements *Pt 12, Ch 3, 7.2 Thrusters – Electrical systems 7.2.1*.

23.11 Hybrid electrical power system components - Source of electrical power

23.11.1 The main source of electrical power is to comply with the requirements of *Pt 16, Ch 2, 2 Main source of electrical power*.

23.11.2 The emergency source of electrical power is to comply with the requirements of *Pt 16, Ch 2, 3 Emergency source of electrical power*.

23.11.3 External sources of electrical power are to comply with the requirements of *Pt 16, Ch 2, 4 External source of electrical power*.

23.11.4 Additional sources of electrical power as defined in *Pt 16, Ch 2, 23.3 Definitions 24.3.4* are to comply with the requirements of this Chapter.

23.11.5 Rotating electrical generators within sources of electrical power are to comply with the requirements of *Pt 16, Ch 2, 9 Rotating machines*.

23.11.6 Converters within power sources are to comply with *Pt 16, Ch 2, 10.2 Semiconductor converters* and the following requirements:

(a) Converters are to be selected to withstand the voltage ripple levels present on the distribution system. For every system, the following voltage parameters are to be defined:
    i. maximum non-repetitive peak;
    ii. maximum repetitive peak; and
    iii. maximum repetitive peak-to-peak.

(b) Where pulse width modulation converters are to be used, the voltage rate of rise times are to be determined, the results recorded and submitted to LR. Rotating machinery, surge protective devices, cable insulation and motor windings are to be designed accordingly.

(c) Converters may be of conversion type a.c./a.c., d.c./a.c., a.c./d.c., d.c./d.c., and can be of the controlled (e.g. active front end (AFE)) or non-controlled type (e.g. diode supply unit (DSU)).

(d) Converters are to be provided with visual status indication at their associated control stations to include, but not be limited to:
    i. power available at the input;
    ii. power at output;
    iii. temperature; and
    iv. overload.

If certain indicators and alerts are not applicable, sufficient evidence to support the claim is to be submitted for consideration by LR. Additional indicators, alerts and shutdowns may be necessary as determined through the system Failure Modes and Effects Analysis (FMEA) required by *Pt 6, Ch 2, 24.27 Power System Development and Integration - System Failure Modes and Effects Analysis (FMEA)*.

(e) Converters supplying electrical power to the distribution system and consumers are to be capable of delivering the required currents for the time required to enable current-time discrimination of protective devices to operate. The electrical output of the converter is to be automatically restored following fault clearance.

(f) Converter software is to satisfy the requirements of *Pt 16, Ch 1, 2 Essential features for control, alarm, monitoring and safety systems*.

(g) Converters are to be capable of handling voltage and current spikes from the distribution system under all normal and reasonably foreseeable abnormal conditions without sustaining any damage or tripping.

(h) Converters supplying essential services are to automatically restart and connect to the distribution system after a blackout as specified in *Pt 16, Ch 2, 2.2 Number and rating of generators and converting equipment*.

(i) Where converters are equipped with internal capacitors which can contribute significantly to the short-circuit level of the system, the contribution is to be included in the design of the protection and distribution system.

(j) The risk of converter component damage due to inrush currents is to be minimised by appropriate management of these currents during transient events and after short circuit.

(k) Where capacitors are connected to a converter output, the output is to be charged by the converter or by external chargers to a level which will minimise the risk of damage to the capacitors before connecting them to the distribution system.

(l) Converters arranged to operate in parallel are to be capable of stable load sharing up to maximum continuous load and inclusive of any temporary overloads within their design rating.

(m) Where converters are arranged to provide protection against electrical faults a disconnector or switch disconnector is to be provided to enable safe isolation of the converter from its incoming supplies.

(n) Converters are to be protected from permanent physical damage as a result of short circuits or overload currents on their input and output terminals.

(o) Converters are to have a ride-through capability to manage system transients including the effects of fault clearance in the distribution system that is consistent with the dependability requirements of the system.

(p) Converters are to be provided with appropriate filters to ensure the required quality of power supply at both their input and output. In the event of filter circuit failure, continued safe operation of the hybrid electrical power system is to be possible by following specified procedures as described in operation procedures. These procedures are to include any operational limitations, and they are to be kept on board, maintained in accordance with *Pt 16, Ch 2, 23.18 Power system development and integration - General 23.18.3* and made available to the Surveyor on request.

23.12 Hybrid electrical power system components - Store of electrical energy

23.12.1 Functional requirements: To provide sufficient stored electrical energy as a component of the main source of power to supply services during normal and reasonably foreseeable abnormal and emergency conditions.

23.12.2 Batteries of the vented and valve-regulated sealed type and lithium batteries are to comply with *Pt 16, Ch 2, 12 Batteries*.

23.12.3 Power converters within stores of electrical energy as illustrated in *Pt 16, Ch 2, 23.3 Definitions 23.3.5* are to comply with the relevant requirements of *Pt 16, Ch 2, 23.11 System components - Power source 23.11.6*.

23.12.4 For consideration as a component of the main source of power on a ship with a specified service notation as defined in *Pt 1, Ch 2, 3.3 Class notations (hull)* and subject to approval of the National Administration a store of electrical energy is to:

(a) Comply with *Pt 16, Ch 2, 23.7 Hybrid electrical power system performance - Main source of electrical power*;

(b) Have a minimum capacity at any stage of its lifecycle sufficient for its contribution to the main source of power that is necessary to achieve the specified service requirements;

(c) Be provided via energy management functionality with remote indication of state of charge (available capacity in a store expressed as a percentage of rated capacity) and state of health (general condition of a store expressed as a percentage of its ability to deliver the specified performance compared with that of a new store);

(d) Have a primary purpose of supplying the ship's main power demand. Details of any secondary purpose including but not limited to optimising performance (e.g. load smoothing, peak shaving), improving stability (e.g. dynamic response) or providing transitional power are to be provided to LR; and

(e) Be capable of being restored from a dead-ship condition with no dependence on other systems or electrical supplies. Details of alternative arrangements may be submitted for consideration by LR.

23.12.5 For consideration as an additional source of power a store of electrical energy is to:

(a) Comply with *Pt 16, Ch 2, 23.7 Hybrid electrical power system performance - Main source of electrical power 23.7.3*;

(b) Be provided via energy management functionality with remote indication of State of Charge (available capacity in a store expressed as a percentage of rated capacity) and State of Health (general condition of a store expressed as a percentage of its ability to deliver the specified performance compared with that of a new store); and

(c) Have a primary purpose of supplying the ship's main power demand. Details of any secondary purpose including but not limited to optimising performance (e.g. load smoothing, peak shaving), improving stability (e.g. dynamic response) or providing transitional power are to be provided to LR.

23.12.6 For application as an emergency source of power a store of electrical energy is to comply with *Pt 16, Ch 2, 23.8 Hybrid electrical power system performance - Emergency source of electrical power*.

23.12.7 Electrical energy storage devices connected to and charged by the distribution system are to be protected against the defined effects of electrical faults in the system.

23.12.8 Energy stores connected to and charged by the distribution system are to be so located and provided with arrangements allowing for the safe isolation of their terminals and the reduction of voltages to a safe level during maintenance or provided with alternative arrangements providing an equivalent level of safety which will be subject to special consideration.

23.12.9 Energy stores are to be connected to the distribution system by protection devices which include but are not limited to overcurrent and short circuit protection. The protective devices used are to be selective, ensuring faults are not transmitted further, independent of the direction of current flow.

23.13 Hybrid electrical power system components - Consumer of electrical power

23.13.1 Functional requirements: To convert electrical power supplied from the hybrid power generation and distribution system into useful work.

23.13.2 Rotating machines within consumers of electrical power are to comply with the requirements of *Pt 16, Ch 2, 9 Rotating machines*.

23.13.3 Converters within consumers of electrical power are to comply with the relevant requirements of *Pt 16, Ch 2, 23.11 System components - Power source 23.11.6*.

23.13.4 Where a converter is arranged to step down voltage to provide a lower voltage supply to consumers than that of the power system then arrangements are to be provided to ensure the lower voltage distribution consumers are not subjected to voltage variations, including fast transients, outside their safe operating regions.

23.13.5 Consumers employing loads characterised by constant power characteristics connected to the distribution system through a converter are to be evaluated with respect to ensuring the stability of the power system as part of the power system analysis detailed in *Pt 6, Ch 2, 24.24 Power system development and integration - Power system analysis*.

23.14 Hybrid electrical power system components - Combined sources of electrical power, stores of electrical energy and consumers of electrical power

23.14.1 Functional requirements: To provide the combined functional requirements of each of the elements (sources, stores, consumers) from which the combination is constructed.

23.14.2 Where a single functional or physical assembly contains a combination of source, store or consume functions then it is to comply with the requirements of each applicable function as detailed in *Pt 16, Ch 2, 23.11 System components - Power source* to *Pt 16, Ch 2, 23.13 System components - Consumer of electrical power*.

23.15 Hybrid electrical power system components - Distribution system

23.15.1 Functional requirements:
(d) To provide a dependable interconnection between sources, stores and consumers of electrical power; and
(e) To distribute electrical power safely to consumers.

23.15.2 Arrangements for isolation and switching are to be provided which are to enable safe isolation of faults and for maintenance.

23.15.3 Distribution systems supplying consumers through converters are to provide galvanic isolation and ground separation.

23.15.4 In addition to the requirements of *Pt 16, Ch 2, 5.3 Isolation and switching*, systems are to comply with the requirements of *Pt 16, Ch 2, 23.15 System components - Distribution system 23.15.5* to *Pt 16, Ch 2, 23.15 System components - Distribution system 23.15.13*.

23.15.5 Where consumers are supplied via converters which are connected to both sides of a distribution system that is capable of being split, arrangements are to be provided to eliminate the risk of current being supplied back to the distribution system for example through flyback diodes.

23.15.6 Converters connecting sources, stores and consumers connected to the distribution system are to facilitate the connection and removal of sources, stores and consumers in a stable manner with the electrical power system in operation.

23.15.7 Converters are to be designed to prevent damage to the converter when switching under load.

23.15.8 Where essential services are required to be duplicated, these are to be served by individual circuits, separated in their switchboard or section board and throughout their length as widely as is practicable without the use of common feeders, protective devices, control circuits or controlgear assemblies, so that any single fault will not cause the loss of both services.

23.15.9 The distribution system is to be split into at least two independent systems each capable of independent operation or is to be separated by protection devices that are selective, ensuring faults are not transmitted further, and operate independent of the direction of current flow.

23.15.10 The distribution system is to be protected against electrical faults including short circuit, overload, earth fault, differential current, under/over voltage, under/over frequency, power quality, current and voltage imbalance, arc fault in compliance with the relevant requirements of *Pt 16, Ch 2, 6 System design - Protection* and *Pt 16, Ch 2, 23.15 Hybrid electrical power system components - Distribution system 23.15.11* to *Pt 16, Ch 2, 23.15 Hybrid electrical power system components - Distribution system 23.15.14*.

23.15.11 Active components may be used for the limitation of fault currents subject to verification in a real environment of the performance of the component under all normal and reasonably foreseeable abnormal operating and fault conditions and subject to establishment of effective surveillance and periodic test procedures during operation and maintenance in the ship’s operating manuals to verify the component is capable of performing its intended function. An isolation device is to be provided within the component and this is to be tripped automatically in the event of the component operating. A risk assessment of the component is to be undertaken to a recognised standard that is acceptable to LR (e.g. ISO 31010*, Risk management – Risk assessment techniques*) and in accordance with *ShipRight Procedure Assessment of Risk Based Designs* and associated annexes.

23.15.12 Where energy management functionality provides protection against incorrect or unexpected energy flows between the sources, stores and consumers forming part of the hybrid electrical power system the sensors used for this purpose in the distribution system are to be independent of those used for control, monitoring and safety systems.

23.15.13 Where a bi-directional flow of power may occur, the distribution system is to withstand the power variations being introduced. The level of bi-directional flow allowed is to be specified by the system designer.

23.15.14 For **Hybrid Power (+)** notation facilities are to be provided for automatic detection of the location of insulation breakdown with respect to earth of equipment and distribution systems to a level determined by the integrator consistent with the system's dependability targets and agreed with the designers and Owners.

23.15.15 For either notation, switchgear and controlgear are to comply with the relevant requirements of *Pt 16, Ch 2, 7 Switchgear and controlgear assemblies*.

23.15.16 Power converters within distribution systems are to comply with the relevant requirements of *Pt 16, Ch 2, 23.11 Hybrid electrical power system components - Power source 23.11.6*.

23.15.17 Where fuses are implemented to limit the fault current in the converter, the activation of the protection is not to influence redundant consumers or cause loss of other single consumers as required by *Pt 16, Ch 2, 5.2 Essential services*.

23.15.18 Fuses used to protect distribution converters are to be of the bolted type. Where alternative arrangements are proposed, it is to be demonstrated that protection system's selectivity is not adversely affected as a result of an increased connection resistance.

23.15.19 For each section of a d.c. bus there is to be at least one voltmeter per section. An ammeter is to be provided for each converter supplying a d.c. bus. Similar arrangements are to be provided for screen-based displays.

23.15.20 The meters required by *Pt 16, Ch 2, 23.15 Hybrid electrical power system components - Distribution system 23.15.19* are to be located and arranged such that they may be viewed at a single operating position. In addition, meters may be required at additional locations to mitigate hazards identified by the risk assessment required by *Pt 16, Ch 2, 23.27 Power system development and integration - System Failure Modes and Effects Analysis (FMEA)*.

23.15.21 Power quality assessments are to consider the detection and impacts of circulating currents such as may exist through capacitive coupling in semiconductor converters.

23.15.22 Constant current distribution systems will be subject to special consideration and are not covered by these Rules.

23.15.23 For **Hybrid Power (+)** notation warnings of degrading power quality are to be provided and in the event of power quality exceeding prescribed limits automatic isolation and reconfiguration of the power system is to occur as agreed between the designers and Owners.

23.16 Hybrid electrical power system components - Energy management

23.16.1 Functional requirements:
(a) To ensure that sufficient energy is available to satisfy the main power demand under all foreseeable operational conditions.
(b) To inform Operators as soon as reasonably practicable of deviations from normal operation of the hybrid electrical power system under all normal and reasonably foreseeable abnormal operational conditions.
(c) To initiate immediate corrective action on detection of component faults in the hybrid electrical power system that present a danger, reducing the risk to a level that is acceptable to LR.
(d) To provide functionality beyond the scope of conventional power management that is necessary for the control, monitoring, protection and dependability of the hybrid electrical power system.

23.16.2 Programmable electronic systems used to provide energy management functionality, or to provide safety functions, are to have arrangements which satisfy the applicable requirements of *Pt 16, Ch 1, 2 Essential features for control, alarm, monitoring and safety systems*.

23.16.3 Proposed modifications to software, including parameter changes, and during acceptance testing and trials are to be in accordance with *Pt 16, Ch 1, 1.4 Alterations and additions* as applicable.

23.16.4 Loss of energy management functionality is not to compromise the supply of main power, the safety of the ship, the hybrid electrical power system, or its components.

23.16.5 Energy management functionality is to include, but not be limited to, the following:
(a) Control (of the complete system and of each of its sub-systems):
    i. hybrid electrical power system operating mode selection and transition;
    ii. connection and disconnection of sources, stores and consumers to the distribution system in response to operating conditions and prevailing loads;
    iii. connection and disconnection of distribution system sections;
    iv. load allocation to and sharing between sources;
    v. load restriction of consumers;
    vi. energy flow management;
    vii. distribution system a.c. voltage and frequency and d.c. voltage; and
    viii. control functions required by sources, stores, consumers or distribution system that are necessary for their operation under all reasonably foreseeable normal, abnormal and fault conditions
(b) Alarm and monitoring:
    i. mode transition status;

    ii. connection status of sources, stores, consumers and distribution system sections;
    iii. energy flows within the hybrid electrical power system and between its constituent parts;
    iv. power quality as detailed in *Pt 16, Ch 2, 23.17 Transversal requirements 23.17.3*; and
    v. for stores, state of charge and state of health as defined in *Pt 16, Ch 2, 23.12 System components - Store of electrical energy 23.12.4* and *Pt 16, Ch 2, 23.12 System components - Store of electrical energy 23.12.5*.

(c) Protection and safety:
    i. blackout prevention;
    ii. blackout recovery;
    iii. detection of abnormal or unexpected energy flow as described in *Pt 16, Ch 2, 23.15 System components - Distribution system 23.15.12*; and
    iv. safety functions required by sources, stores, consumers or distribution system that are necessary for their safe operation.

23.16.6 Overall ship-wide energy management functionality is to be integrated and coordinated with the functionality of the local management systems as described in *Pt 16, Ch 2, 23.3 Definitions* for each of the components (sources, stores, consumers, combinations, distribution system) of the hybrid electrical power system and is to ensure safe operation of the ship under all normal and reasonably foreseeable abnormal operating and fault conditions.

23.16.7 Additional energy management functionality for **Hybrid Power (+)** notation is to consider, but not be limited to, the following. The level of functionality supplied is to be consistent with the enhanced performance and dependability required by the system.

(a) Control (of the complete system and of each divisible element):
    i. automatic configuration of the power system based on predicted energy flow;
    ii. automatic system isolation and reconfiguration such that, in the event of a single failure in electrical power sources, stores, distribution system or associated control systems, the impact on the operational performance of the ship is as agreed with LR and there is no impact on the ship's ability to complete its mission;
    iii. system performance optimisation, independent of primary control functions covering emissions, efficiency, availability, reliability or operating cost; and
    iv. control of stores with load smoothing, peak shaving, dynamic response or other optimisation capability.

(b) Alarm and monitoring:
    i. degradation of power quality;
    ii. remaining time for continued operation of the power system at current operating conditions and levels of power consumption. This may take the form of a real-time performance capability plot;
    iii. system performance covering energy consumption, emissions, efficiency, availability, reliability or operating cost; and
    iv. health and condition of hybrid electrical power system components including the effects of ageing on electrical energy storage devices.

(c) Protection and safety:
    i. automatic isolation and reconfiguration of the power system on detection of abnormal energy flow;
    ii. consequence analysis determining the remaining time for continued operation of the power system under stated operating and load conditions following the most significant single failure. This may take the form of an onboard off-line simulation derived from, or an integral element of, the simulation described in *Pt 16, Ch 2, 23.23 Power system development and integration - Energy flows 23.23.3*; and
    iii. automatic detection of faults detailed in the system level FMEA with display of mitigating actions.

23.16.8 A description of functionality including also any functions not described in *Pt 16, Ch 2, 23.16 Hybrid electrical power system components - Energy management 23.16.5* and *Pt 16, Ch 2, 23.16 Hybrid electrical power system components - Energy management 23.16.7* is to be submitted.

23.17 Transversal requirements

23.17.1 All electrical equipment is to prevent injury to personnel or damage to other equipment and is to be suitably protected against damage to itself under normal, reasonably foreseeable abnormal and fault conditions.

23.17.2 The supply of electrical power sufficient for the correct operation of electrical services for essential equipment and habitable conditions is to be maintained:

(a) during all normal and reasonably foreseeable abnormal operating and fault conditions;
(b) irrespective of the direction of the propulsion shaft rotation; and
(c) without any requirement to revert to emergency supplies.

23.17.3 Hybrid electrical power systems are to provide a power quality as required by;

- *Pt 10, Ch 1, 7.3 Auxiliary engine governors*,
- *Pt 16, Ch 2, 1.8 Quality of power supplies*,
- *Pt 16, Ch 2, 2.4 Prime mover governors* and
- *Pt 16, Ch 2, 9.4 Generator control*

during all normal and reasonably foreseeable abnormal operating and fault conditions.

23.17.4 A.c. and d.c. systems are during all normal and reasonably foreseeable abnormal operating and fault conditions to provide a quality of power as required by a recognised National or International Standard specified by the power system integrator that is acceptable to LR.

23.17.5 All components of or connected to the distribution system are to be designed and validated for operation across the full range of power quality conditions detailed in *Pt 16, Ch 2, 23.17 Transversal requirements 23.17.2* to *Pt 16, Ch 2, 23.17 Transversal requirements 23.17.4*.

23.17.6 The key parameters of power quality as determined by the system integrator with agreement of the owner and as applicable to the type of electrical power system are to be monitored and recorded for each individually operable section of the distribution system. An alarm is to be raised at a monitored operating station in the event of power quality exceeding limits determined by the system integrator in compliance with the power quality requirements of the rules. A description of the arrangements provided is to be submitted.

23.17.7 For either notation, all electrical equipment is to comply with the requirements of *Pt 16, Ch 2 Electrical Engineering* including:
(a) general requirements - *Pt 16, Ch 2, 1 General requirements* including fire, electric shock, ignition, radiation, fire, environment;
(b) creepage and clearance - *Pt 16, Ch 2, 7.5 Creepage and clearance distances*;
(c) arc - *Pt 16, Ch 2, 8 Protection of personnel from hazards resulting from electric arcs within electrical equipment and enclosures*; and
(d) explosive atmospheres - *Pt 16, Ch 2, 14 Electrical equipment for use in explosive gas atmospheres*.

23.17.8 The choice of materials and components of construction, as well as the design, location and ship installation, are to be made according to the environmental, maintenance and operating conditions in order to maintain the continued function of the equipment during all normal and reasonably foreseeable abnormal conditions and to reduce the risk of:
(a) injury to onboard personnel;
(b) damage to the equipment the system is contained within or adjacent equipment and systems;
(c) damage to adjacent equipment and systems; and
(d) damage to the ship.

23.17.9 Where applicable, equipment and components are to be selected from the list of LR type approved products satisfying the requirements of *Pt 16, Ch 1, 1.4 Control, alarm and safety equipment* and *Pt 16, Ch 1, 2.13 Programmable electronic systems - Additional requirements for essential services and safety critical systems*.

23.17.10 Electrical equipment is to be used within its designed operating parameters, such as current, voltage, power, charging rate, energy storage, etc. to prevent:
(d) a hazard occurring; and
(e) the equipment affecting safety functions.

23.17.11 All electrical equipment supplied from the main and emergency sources of electrical power and electrical equipment for essential and emergency services is to be selected to operate satisfactorily under the variations of voltage and ripple frequencies which may be present in the system.

23.17.12 Cables and busbars are to be selected and installed in accordance with *Pt 16, Ch 2, 11 Electric cables, optical fibre cables and busbar trunking systems (busways).*

23.17.13 Transformers within the hybrid electrical power system are to comply with the relevant requirements of *Pt 16, Ch 2, 10.1 Transformers*.

23.17.14 Interlocks or an alternative acceptable to LR are to be provided which will prevent access to capacitors until their voltage level has reduced to below the safe extra low voltage level (50 V); this is to ensure safety of personnel during maintenance.

23.18 Power system development and integration - General

23.18.1 The activities specified in *Pt 16, Ch 2, 23.19 Power system development and integration - System operational concept* to *Pt 16, Ch 2, 23.31 Verification requirements* are to be undertaken to deliver and maintain a safe and dependable hybrid electrical power system throughout its development, detail design, construction, integration, verification and acceptance. Procedures are to be made available detailing how these activities will be maintained during ship operation, maintenance and disposal.

23.18.2 The activities should be based on the principles of the following five levels with measures adopted at each level being, as far as practicable, independent of each other:
(a) Prevention of abnormal operation and failures though design and high quality in construction, operating rules and normal operating procedures;
(b) Control of abnormal operation and detection of failures through control, limiting and protection systems, monitoring/surveillance features and abnormal/emergency operating procedures;
(c) Control of hazards within the system design to protect against escalation to an incident or accident through engineered safety features and emergency operating procedures;
(d) In support of and coordinated by the Owner and ship designer, control of severe ship or infrastructure conditions that may exceed the system design intent including prevention of hazard progression and mitigation of hazardous consequences through complementary procedures and hazard management; and
(e) In support of and coordinated by the Owner and ship designer, mitigation of accident consequences through emergency response.

The system designer is to ensure adoption of principles (a) to (c) during the development and integration of the hybrid electrical power system providing evidence to LR through the documentation that is submitted for design review as detailed in *Pt 16, Ch 2, 1.2 Documentation required for design review 1.2.13.*

23.18.3 At each phase of a project integration activities are to be managed by a suitably competent single designated party and are to be carried out in accordance with a defined procedure identifying the roles, responsibilities and requirements of all parties involved.

23.18.4 Where the designated party changes during a project then there is to be a full and auditable transfer of necessary integration information between the parties.

23.18.5 Systems engineering processes are to comply with *ISO 15288 Systems and Software Engineering – System Life Cycle Processes* or an acceptable equivalent National or International Standard.

23.19 Power system development and integration - System operational concept

23.19.1 The system operational concept is to be defined including a description of how the control, alarm and safety systems for the hybrid electrical power system provide effective means for operation and control during all defined ship operational conditions.

23.19.2 The system operational concept is to detail the capability, functionality and modes of operation under defined operating and emergency conditions and is to be agreed between the designers and Owners.

23.19.3 The system operational concept is to be submitted for design review.

23.20 Power system development and integration - Operating modes

23.20.1 Operating modes for the hybrid electrical power system are to be defined and agreed between the designers and Owners.

23.20.2 Modes are to cover all normal and reasonably foreseeable abnormal operating and fault conditions.

23.20.3 Modes are to be compatible with the ship's overall operating modes.

23.20.4 The sequence of transition between operating modes is to be defined for all normal and reasonably foreseeable abnormal operating and fault conditions.

23.20.5 A technical description is to be produced specifying for each of the ship's possible operating modes:
(a) the type of each electrical power source used to supply the distribution system, such as a.c. generators, d.c. generators, converter, batteries, fuel cells and photovoltaics;
(b) the operating mode of each electrical power source such as constant voltage, constant current or variable voltage;
(c) the configuration of the electrical distribution system, including the earthing and protection strategies to be used; and
(d) the worst-case failure design intent.

23.21 Power system development and integration - Consumer categorisation

23.21.1 Consumers supplied with electrical power from the hybrid electrical power system are to be categorised according to their function and the services that they provide in accordance with the requirements of *Pt 16, Ch 2, 1.6 Definitions*.

23.22 Power system development and integration - System components

23.22.1 The specifications for all components of the hybrid electrical power system (sources, stores, consumers, distribution system, energy management) are to be validated by the system designer for completeness and correctness in respect of the component's integration into the overall power system. Validated specifications are to be submitted to LR.

23.22.2 Details of the following are to be specified:
(a) operating modes and the transition between them;
(b) control and monitoring functions;
(c) mechanical components which might affect the hybrid notation (e.g. cooling units with piping arrangements, pumps, valves, etc.);
(d) safety functions;
(e) failure modes;
(f) isolation;
(g) initial and through-life verification of conformance; and
(h) human element.

23.23 Power system development and integration - Energy flows

23.23.1 Energy flows within the hybrid electrical power system are to be determined for all operating modes and all normal and reasonably foreseeable abnormal operating and fault conditions.

23.23.2 The impact of transition between modes on energy flow is to be considered.

23.23.3 For **Hybrid Power (+)** notation energy flow is to be modelled by a dynamic simulation that can be exercised under normal, reasonably foreseeable abnormal operating and fault conditions and that is maintained for the life of the ship. This simulation may be deployed on board as described in *Pt 16, Ch 2, 23.16 Hybrid power system components - Energy management 23.16.7* in support of off-line consequence analysis.

23.23.4 Simulation tools are to conform to appropriate National or International Standards relevant to their use and are to have been validated in an equivalent application.

23.23.5 The dynamic simulation is to be verified against the energy flows encountered during the ship's real performance to the extent that this is reasonably practicable.

24.23.6 Proprietary simulation tools not conforming to an appropriate National or International Standard will be subject to special consideration. This consideration will include:
(a) pedigree of the underlying modelling platform on which the simulation is built;
(b) qualitative assessment of the simulation's functional capabilities and model behaviours;
(c) configuration management of the simulation model, its architecture, functional blocks and the parameters on which it is based;
(d) prior quantitative assessment of the simulation's performance in a similar application; and
(e) an engineering justification that the validation and verification of the simulation is sufficient to enable its application in all normal and reasonably foreseeable abnormal operating and fault conditions.

23.24 Power system development and integration - Power system analysis

23.24.1 The hybrid electrical power system is to be analysed for its electrical performance under all defined operating modes and all normal and reasonably foreseeable abnormal operating and fault conditions.

23.24.2 The analysis is to include, but not be limited to:
(a) fault levels under short circuit conditions;
(b) fault flows under short circuit and overload conditions;
(c) protection device operation, discrimination and coordination;
(d) quality of power supplies;
(e) steady state performance;
(f) transient performance;
(g) earth fault currents;
(h) resonance; and
(i) common mode and circulating currents.

23.24.3 Information regarding the expected resistance, inductance and capacitance in the system and the installed components is to be provided as part of the analysis study as required by *Pt 16, Ch 2, 1.2 Documentation required for design review*. The values chosen are to be based upon the component tolerances which result in the worst case for each aspect of the analysis and are to be updated with actual values when determined from component, sub-system or system test.

23.24.4 For **Hybrid Power (+)** notation the analysis is to be by a dynamic simulation that can be exercised under all normal, abnormal and fault conditions, that is maintained for the life of the ship and that can be exercised to verify operation of the protection system including:
(a) short circuit, single or multiple phases/poles;
(b) overload;
(c) overcurrent;
(d) current imbalance;
(e) voltage imbalance;
(f) zone protection;
(g) arc fault;
(h) earth fault;
(i) under/over voltage;
(j) under/over frequency;
(k) harmonic content;
(l) quality of power supplies including degradation detection;
(m) energy flow including any regeneration by consumers;
(n) resonance and stability;
(o) transient impact of fault detection, clearance and isolation;
(p) transient impact of sources, stores and consumers being tripped or shut down;
(q) transient impact of load changes, both increase and decrease; and
(r) load sharing imbalance.

23.24.5 Simulation tools are to conform to appropriate National or International Standards relevant to their use and are to have been validated in an equivalent application.

23.24.6 The dynamic simulation is to be verified against the ship's real performance to the extent that this is reasonably practicable.

23.25 Power system development and integration - Safety functions

23.25.1 Safety functions related to the hybrid electrical power system and its constituent parts are to be clearly defined covering their purpose, their functionality and their location.

23.25.2 Safety functions are to comply with *Pt 16, Ch 1, 2 Essential features for control, alarm, monitoring and safety systems*.

23.25.3 Safety functions including ESD, emergency stop and reversionary control procedures for the hybrid electrical power system are to be defined, fully documented and made available to the Operators, maintainers and regulatory authorities.

23.26 Power system development and integration - Risk assessment

23.26.1 Where the hybrid electrical power system introduces new technologies or topologies not covered by the current Rules and Regulations then a risk assessment study is to be carried out.

23.26.2 A formal method acceptable to LR is to be used to determine if new hazards or significantly greater hazards than those normally associated with the ship electrical power system that would be mitigated by compliance with the Rules and Regulations have been introduced (e.g. a preliminary hazard analysis or a structured checklist approach (HAZID) in accordance with ISO 31010, *Risk management – Risk assessment techniques*).

23.26.3 Where the results of this formal method establish that new hazards or topologies exist the risk assessment study is to be undertaken to a recognised standard that is acceptable to LR (e.g. ISO 31010*, Risk management – Risk assessment techniques*) and in accordance with *ShipRight Procedure Assessment of Risk Based Designs* and the associated annexes.

23.26.4 The objectives of the study are to:
(a) identify potential deviations from the intended operation of the hybrid electrical power system;
(b) identify the causes of each deviation, and the consequences for safety and dependability;
(c) list safeguards to minimise causes and consequences; and
(d) determine and recommend if further safeguards should be considered.

23.26.5 The scope of the study is to consider normal operation, start-up, normal shutdown, non-use and ESD of the hybrid electrical power system.

23.26.6 The risk assessment technique(s) selected are to be appropriate for their intended use and are to be accepted by LR.

23.27 Power system development and integration - System Failure Modes and Effects Analysis (FMEA)

23.27.1 An overall hybrid electrical power system FMEA is to be undertaken. The objectives of the analysis are to identify:
(a) potential failures;
(b) consequences of failure on the hybrid electrical power system and on ship operations;
(c) means to eliminate or prevent failure; and
(d) means to eliminate or minimise consequences.

23.27.2 The analysis may identify the requirement for safety measures in addition to those specifically stated in these Rules. Where additional safety measures are identified, evidence is to be provided that demonstrates how they are implemented and validated.

23.27.3 As a minimum, the scope of the analysis is to consider the 'fail safe' condition, location and arrangement of the critical system elements.

23.27.4 The analysis is to be undertaken to a recognised standard (e.g. IEC 60812*, Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)*) or an equivalent and acceptable National or International Standard.

23.27.5 The FMEA is to consider but not be limited to:
(a) hidden faults that are not annunciated to or evident to the Operator where a second subsequent fault can directly result in a significant failure and hazardous condition;
(b) foreseeable inadvertent operation of the hybrid electrical power system;
(c) failure to complete transition sequences (e.g. change of operating mode or response to a fault including its detection, clearance, isolation and reconfiguration);
(d) items which can be dormantly failed and unavailable to perform their intended operation on demand (e.g. normal to backup changeover systems or standby start systems);
(e) enabling systems not part of the hybrid electrical power system (e.g. fuel supply, lubrication, cooling and ventilation systems) whose failure could affect correct functioning of the hybrid electrical power system;
(f) sensor and feedback errors in programmable electronic systems;
(g) parameter corruption in programmable electronic systems (e.g. incorrect scaling factors, control rates, alarm thresholds or trip levels);
(h) common cause effects in programmable electronic systems (e.g. network storms in networked systems, power supply faults, time dependent errors in operating systems with the potential to concurrently impact multiple redundant control or monitoring systems);
(i) common cause effects in electrical power systems (e.g. power quality outside expected range or multiple earth faults in a parallel connected system);
(j) consequential failures resulting from a single failure that are to be considered as an integral part of the single failure; and
(k) the viability of the role of the human in the detection and mitigation of faults.

23.27.6 Examples of devices in which hidden failures can occur that are detrimental to the dependability of a hybrid electrical power system include but are not limited to:
(a) protection devices – protection relays, dead-bus sensing;
(b) automatic isolation devices;
(c) circuit breaker open/close/trip functions;
(d) fault/current limitation devices;
(e) arc detection;
(f) load shedding devices;
(g) safety devices;

(h) fault detection systems;
(i) alternator current boost systems;
(j) interlocks and inter-trips;
(k) automatic change-over systems, transfer and dual-feed arrangements;
(l) stand-by start arrangements;
(m) transducers/sensors – giving an incorrect output;
(n) slow processors (e.g. watchdog functions);
(o) UPS backed-up supplies; and
(p) active failures of control systems – working but not doing what was intended.

23.27.7 Hybrid electrical power system failure modes identified through the FMEA that could impact the safe operation and performance of any component of the system (source/store/consumer/combination/distribution system/energy management) are to be notified to, and acknowledged by, the party accountable for the safety of the component through an auditable process.

23.27.8 Component failure modes that could impact the safe operation and performance of the hybrid electrical power system are to be notified to, and acknowledged by, the hybrid electrical power system integrator through an auditable process.

23.27.9 For **Hybrid Power (+)** notation FMEAs for each of the key components of the system may be requested by LR in support of the system FMEA.

23.28 Power system development and integration - Operating instructions

23.28.1 Operating Manuals are to be provided on board and submitted for information where requested by LR. The manuals are to include, but not be limited to, the following information:
(a) particulars and a description of the systems;
(b) operating instructions for the equipment and systems (including fire isolation aspects);
(c) maintenance instructions for the installed arrangements, including procedures to prevent injury from electric shock and arc flash;
(d) software configuration management procedures which are to include a list of all versions of the software installed in the system, and the settings, values of system or equipment specific configuration parameters; and
(e) output from the risk assessment processes that is necessary for the safe operation of the system under all normal and reasonably foreseeable abnormal operating conditions.

23.28.2 Overall hybrid electrical power system operating instructions are to be verified by the system designer for their completeness and correctness in all operating modes and for all foreseeable normal and abnormal operating and fault conditions. The verified instructions are to be submitted to LR.

23.28.3 Consistency between the overall system instructions and those for each component of the system is to be confirmed by the system designer.

23.28.4 All mitigating actions arising from the FMEA that require manual intervention are to be confirmed as included in the operating instructions.

23.28.5 Procedures for reversionary (e.g. manual) control of the hybrid electrical power system are to be included and are to be verified during practical operation.

23.29 Power system development and integration - Operator training

23.29.1 Training needs specific to the ship and necessary for its safe operation are to be identified and documented in the ship's operating manual.

23.29.2 For **Hybrid Power (+)** notation any ship-specific Operator training is to be verified by the system designer for its completeness and correctness in all operating modes and for all foreseeable normal and abnormal operating and fault conditions with evidence of verification submitted to LR.

23.30 Power system development and integration - Through-life accountability

23.30.1 The activities detailed in *Pt 16, Ch 2, 23.18 Power system development and integration - General* to *Pt 16, Ch 2, 23.29 Power system development and integration - Operator training* are to be maintained throughout the whole lifecycle of a ship and are to be verified at Periodic Survey.

23.30.2 Proposed changes to the hybrid electrical power system including its components that may impact on system safety or dependability are to be formally reviewed and accepted by the system integrator before their incorporation with details submitted to LR.

23.30.3 For **Hybrid Power (+)** notation details of incidents arising during any and all operations of the hybrid electrical power system that has, or could have, resulted in a hazardous consequence for people, platform or the environment are to be monitored.

23.31 Verification requirements

23.31.1 Compliance with the requirements in *Pt 16, Ch 2, 1.2 Documentation required for design review 1.2.17* is deemed to satisfy the functional requirements and performance requirements above.

23.32 Testing and trials

23.32.1 Testing and trials in accordance with *Pt 16, Ch 2, 21 Testing and trials* are to be carried out as applicable.

23.32.2 Where required by the *Rules and Regulations for the Classification of Special Service Craft, July 2019*, items are to be constructed under survey.

23.32.3 Materials are to be approved, manufactured and tested in accordance with a standard acceptable to LR.

23.32.4 The fault ride-through capability of the system is to be demonstrated during practical tests on the system.

23.32.5 Quality of power supply testing of the system and the components is to be carried out to prove the equipment is capable of operating under the variations specified by the hybrid electrical power system integrator and accepted by LR for all normal and reasonably foreseeable abnormal operating conditions.

23.32.6 Where considered necessary by LR, additional testing may be required.

23.32.7 Satisfactory operation and load testing of the hybrid electrical power system in harbour and during sea trials are to be witnessed by LR.

23.32.8 Measurements are to be taken as part of the trials to verify that the installation will provide a quality of power supply in accordance with the values declared by the hybrid electrical power system integrator as described in *Pt 16, Ch 2, 23.17 Transversal requirements*.

23.32.9 For **Hybrid Power (+)** notation additional trials are to be carried out to:

(a) Verify that the system delivers the determined levels of performance as described in *Pt 16, Ch 2, 23.5 Hybrid electrical power system performance - System performance targets*;
(b) Verify that the system fulfils the redundancy principles defined by the hybrid electrical power system integrator as described in *Pt 6, Ch 2, 23.6 Hybrid electrical power system performance - Dependability principles*;
(c) Verify the correct operation of the additional energy management functionality described in *Pt 16, Ch 2, 23.16 System components - Energy management*;
(d) Verify that the system performs in accordance with its simulation(s) as described in *Pt 16, Ch 2, 23.23 Power system development and integration - Energy flows* and *Pt 16, Ch 2, 23.24 Power system development and integration - Power system analysis*; and
(e) Verify the findings of the FMEA analysis detailed in *Pt 16, Ch 2, 23.27 Power system development and integration - System Failure Modes and Effects Analysis (FMEA)* and the response of the system to simulated failures.

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